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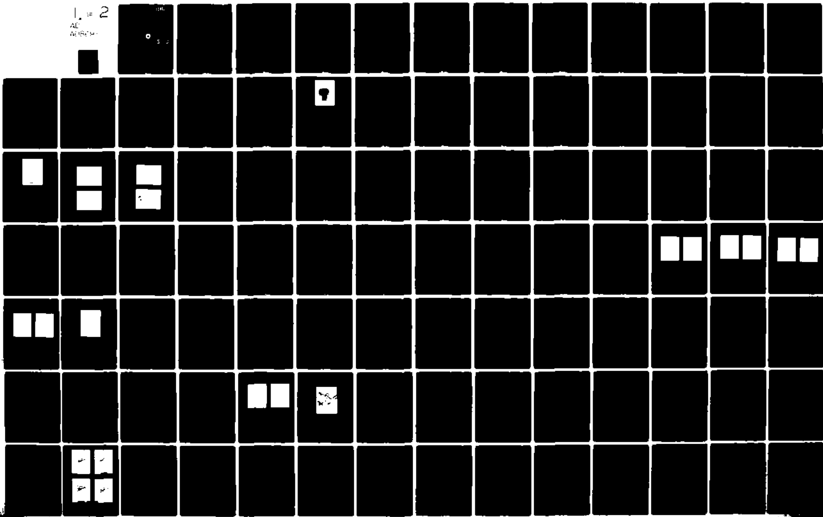

Report No. FAA-RD-80-29

LEVEL II

MOVING TARGET DETECTOR DATA UTILIZATION INVESTIGATION

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F. R. CASTELLA
M. J. FEIL
J. T. MILLER
C. L. ROE

FLEET SYSTEMS DEPARTMENT
THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD • LAUREL, MARYLAND • 20810

JHU/APL/FP9-T-041

Data analysis rept. 1975-1976

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16. Abstract

The Moving Target Detector (MTD), developed by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory under contract to the Federal Aviation Administration (FAA), was designed as an improved video processor for use with the Airport Surveillance Radars (ASRs) within the Automated Radar Terminal System (ARTS) III automated Air Traffic Control (ATC) system. This device interfaces between the analog radar system and the digital automatic tracking system to provide automatic target detection and false alarm regulation. In addition to range, bearing, and amplitude data, the MTD provides doppler information on detected targets. This data is in the form of unconsolidated reports that are to be centroided and tracked to provide a primary radar data base for ATC functions.

In order to evaluate the potential benefits of this MTD data on the ATC tracking operation, a study was conducted at the Applied Physics Laboratory/The Johns Hopkins University (APL/JHU) using experimental data gathered by the FAA and Lincoln Laboratory with an FPS-18 radar at the National Aviation Facilities Engineering Center (NAFEC) during the summer of 1975. The principal investigations focus on two areas: the development of a centroid algorithm for extracting significant target features and ~~the utilization of~~ these features within the subsequent tracking function.

The results of this study indicate that, if properly utilized, the MTD data can significantly enhance the operation of the ARTS III automated ATC system particularly through the suppression of invalid track reports and the improvement in detection of aircraft in the clear and over clutter. Valid MTD doppler data provides the potential, if incorporated into the tracker algorithm, to improve prediction accuracies. Also, the substantial informational content of the MTD primitive reports provides an effective technique for reducing tracker loads, discriminating between clutter and target returns, and detecting second-time-around targets.

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METRIC CONVERSION FACTORS

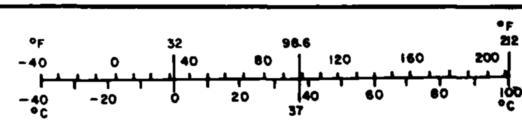
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

In recent years the Federal Aviation Administration (FAA) has been actively seeking techniques for automating the use of primary radar data with the ARTS III air traffic control system. Efforts have principally centered around developing an appropriate interface, or digitizer, between the analog primary radar sensor and the digital compute elements of the ARTS III system. In particular, this digitizer must be capable of assuring a high detection probability for aircraft within the surveillance region while rejecting clutter returns from land, sea, and weather. Further, in the presence of clutter such as that generated by weather, the digitizer must not produce such high numbers of false alarms as to overload the data link between the digitizer and the compute elements and the false alarms produced must be of such a nature as to minimize the generation of false tracks and hence not overload the tracking function. Thus the digitizer must be capable of regulating the false alarms fed to the compute elements.

Several digitizers have been investigated which satisfy these criteria in one way or another although Lincoln Laboratory's Moving Target Detector (MTD) is considered the most viable of the candidate digitizers. It is capable of both regulating false alarms while providing significantly higher target detection probability and tracking capability than the other digitizers. In addition, besides providing these features, MTD generates considerable additional information about the returns than the other digitizers; i.e., amplitude and doppler information. Thus for MTD the potential exists that by properly utilizing this additional information within the compute elements that even more benefits can be achieved in the form of improved track accuracy, significantly reduced processor loads, etc. It is also conceivable that some of this additional data is redundant or of little use, and may be deleted.

The purpose of this study is to explore these potential benefits by developing techniques for utilizing this additional MTD data within the ARTS III system, the size of the improvements or benefits to be accrued by utilizing these techniques, and to indicate possible additional avenues for future exploration which may prove of benefit to the FAA.

2.0 SUMMARY OF RESULTS

Although numerous detailed results are presented throughout this document, the principle result is that there is considerable useful information contained in MTD primitive reports beyond the ordinary range and bearing information. These primitive reports consisted of two types of words, PRF Azimuth Words (PAZ), and Velocity Range Strength Words (VRS). The PAZ words are outputted at the beginning of every Coherent Processing interval (CPI; i.e., 10 pulses), indicating the antenna azimuth and the PRF of the current CPI. The VRS words contain the doppler filter number (0-7), the range (1/16 nmi), and strength (amplitude) of the filter generating a response of sufficient strength to surpass the adaptive threshold.

Some of this new information extracted by the MTD is contained in the data format; i.e., the nature of the data, such as the structure which allows second time around target detection. Most of this information, however, is contained in the doppler and amplitude information generated by the MTD, the general uses for which are documented in the text using the NAFEC tapes as a data base and which are submitted in the following paragraphs.

a) Amplitude and doppler data can be effectively used to identify air target returns and returns from clutter (i.e., "clutter-like" returns), a process which simplifies subsequent tracker loads. Two principal features were found most effective in centroiding process; i.e., the number of Coherent Processing Intervals used, and the maximum number of Velocity Range Strength words per range bin, with the latter being a slightly stronger discriminant, particularly against angels. Statistics indicate clutter returns are dominated by single CPI returns (~76%) while targets consist predominantly of multiple CPI and multiple maximum VRS returns. Maximum range extent also appears to be a useful discriminant.

b) These discriminants developed using amplitude and doppler bin data appear to significantly reduce (10 to 1 or more) tracker loads when used to inhibit tracks initiation on clutter-like centroids. Principally, tentative track counts are reduced with virtually no effect on firm air tracks.

c) Although the "clutter-likeness" of centroids can be used to reduce tracker loading during the track initiation phase, "clutter-like" centroids must be available to update already existing firm tracks. This is a result of the fact that due to various phenomena, such as multipath, etc., real targets occasionally (about 14% of the time for the data tapes) appear clutter-like. Complete deletion of these centroids from tracker processing can result in track degradation or loss even when valid target returns were available.

d) Approximately 83% of the firm track centroids considered had returns for both high and low prfs, thus presenting the opportunity for calculating a measured doppler velocity. Of these measured doppler velocities, approximately 84% of these represent valid velocity measurements. Hence, approximately 70% at the time one can expect valid doppler velocity data to be generated by MTD for air tracks. Invalid velocity data can be eliminated via use of various centroid features and/or the use of tracker estimated radial velocities.

e) A simple table look-up procedure was developed which provides a quick and efficient technique for developing doppler velocity from the MTD doppler bin data.

f) An effective technique was developed for detecting second time around target centroids on a per scan basis, reducing tracker loads.

g) Some anomalous returns were detected in the data tapes and found to be characteristic of a repeater jammer.

In addition to the results developed using the NAFEC data tapes, several other potential benefits were explored theoretically but not verified using real data due to a lack of time. These results are indicated next.

a) Occasionally, amplitude or doppler inconsistency flags were set for targets flying over regions of clutter. These flags indicated that the centroid resulted from MTD primitive reports which were not consistent from range bin to range bin or azimuth sample to azimuth sample or both. The implication is that some of the primitive reports were generated by clutter and some were generated by the target itself, with resulting centroid being composed of reports from both. Hence centroid accuracy has been degraded with corresponding impact on the tracker stores. These flags were set approximately 1.5 percent of the time indicating a small but possibly significant effect due to these overlapped returns.

It was desired to investigate these centroids in detail to assess the potential for modifying the centroiding algorithm during these cases and perhaps decompose these centroids into separate but consistent centroids. Presumably the resulting procedure would be effective in pulling target reports from clutter or in resolving crossing and overlapped tracks.

b) The use of doppler velocity data within the tracker update function was investigated theoretically and found to significantly reduce the variance of the radial velocity estimate for maneuvering targets. The impact of using this new parameter on the improvement in the vector velocity estimate and hence on prediction capability was not completed either theoretically or experimentally.

c) A discriminant for detecting the presence of JEM or prop modulation distortions was investigated theoretically. This technique, labeled spectral purity, was found theoretically effective although it needs verification with the NAFEC data and simplification for practical implementation.

Finally, several possible additional important benefits were considered for study but were not developed theoretically or experimentally due to time constraints and/or the lack of appropriate data, lack of theoretical development, or lack of appropriate software at the time of completion of this effort.

a) The use of amplitude data in developing the range and bearing estimates from the primitive reports has been shown by Lincoln Laboratory to improve the accuracy of the resulting tracks for several selected tracks. It would be desirable to expand this data base by using more tracks, a tracker optimized for MTD data, and taking full advantage of all the information available; i.e., the MTD doppler velocity tracker. The resulting accuracies have significance for the design of the ultimate tracker through the selection of gate sizes and filter gains. Thus it is important that these quantities be accurately measured.

b) Once an MTD doppler velocity tracker is developed it becomes possible to assess the increased maneuver following capability of such a tracker, if any. This would provide verification of the theoretical treatment given in Section 12 and indicate the necessity for doppler velocity information.

c) Other studies developed by APL for the FAA (see Reference 6) have indicated considerable use can be made of doppler data for generating weather information. In particular, preliminary studies indicate properly thresholded primitive report data is a rich source of weather information. Potentially this data may be extracted via a modification of the MTD hardware and the microprocessor software.

d) Long term properties of target returns were not investigated although the total number of doppler bins, the maximum amplitude, the maximum number of doppler bins, etc. are candidates for such a study. (Second time around properties of tracks, however, were found to persist as would be expected.) Such features may prove useful in identifying proximate targets or during turning situations in clutter.

3.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion of the study is that the structure of the primitive reports and the amplitude and doppler characteristics of these reports are of considerable use in identifying and tracking targets in the surveillance region. The benefits of using these data, particularly in the track initiation logic of the ARTS III tracker, are sizeable and can produce considerable savings in both computer core and time requirements over those developed for other digitizers or for the MTD digitizer not making use of this data.

This study indicates that principal use of this data should be made within the centroiding function minimizing the data transfer to the compute elements while utilizing the resultant centroid data within the tracking function to select data for rejection or inclusion in the track data stores.

Measured doppler velocity would appear to be a useful quantity for improving track quality, at least theoretically, and appears to be available about 70% of the time. The results here are not conclusive, however.

The use of four prfs to eliminate second time around targets appears to be an unnecessary complication as the primitive reports on a given scan along with the restricted track initiation logic can be used to eliminate such targets within a 2 prf schedule. Should some other tracking scheme be used, however, these four prf may have to be retained.

Finally, based on the results presented and on the understanding of the system gained as a result of this study, several additional potential applications of this data to characterize the nature of tracks and generate weather data appear feasible. These efforts along with the completion of the detail study as outlined in Section 6, including the design and testing of an MTD doppler velocity tracker, need to be performed to realize the full benefit of this digitizer within the ARTS III system.

4.0 OUTLINE OF THE REPORT

The principal goal of this effort, i.e., investigate potential benefits to be derived from the utilization of the amplitude and doppler data generated by MTD, is pursued in the following sections. The nature and origin of the basic MTD data is presented in the references (1 and 2) as is a description of the digitizer itself. These documents represent the primary base from which the theoretical aspects of the study were initiated. Section 2 summarizes the major results of this study to date, while Section 3 summarizes the conclusions based on these results which are applicable to the use of MTD within the ARTS III system. Section 5 presents a short history of the evolution of this digitizer to the present and indicates the need for this study presented herein.

Based on these documents, on previous experience with similar military systems (such as the Navy's Target Acquisition System, TAS), on theoretical models of target and clutter developed during previous efforts involving the FAA primary radar (ASR-7) (see References 3, 4, and 5 for example) and on an intuitive understanding of the nature of the ASR radar environment, an overall study effort was devised. This effort, outlined in detail in Section 6, covers the complete range of investigations needed to fully develop the potential benefits of this new data. In particular, the effort was designed to explore the usefulness of these data at each step in the ARTS III processing; i.e., from raw primitive data centroiding to the generation of track data files. This report follows that outline; i.e., each section (except for Section 12 which consolidates several theoretical studies) details the potential impact or benefits to be gained at each step in the processing, starting with primitive report properties and ending with MTD track characteristics.

Due to the timeliness of the desired output from this effort, several studies were overlapped with constant cross feeding of findings between the studies. Even so, the complete study as outlined in Section 6 was not completed due to time limitations, though the additional studies required to complete the study are indicated in the text.

During the development of the effort detail sample digital MTD primitive extract tapes generated during a test effort at the FAA's NAFEC test facility became available. These tapes were used throughout the study to develop and explore the properties of these amplitudes and doppler data, and to verify the magnitude and viability of the various techniques developed on real data.

Section 7 presents the results developed during a study of these raw MTD primitive extract tapes, the object of which was to observe the primitive reports for properties which may be of use in the ARTS III processing. This study is essential as useful properties may become distorted or completely deleted if only data after centroiding is investigated.

Section 8 describes an experimental centroiding algorithm based on simple proximity assumptions for combining primitive reports for a target into one centroid. The algorithm is designed to be quite general and retains a considerable number of parameters for study, not all of which proved useful. Parameters were selected based on observations of the primitive data using printouts, displays, etc. (see Section 7), theoretical models, and intuition. Although the object of the study was to study all the parameters and their combinations, only a few of the obviously more significant parameters (and their combinations) received a detailed study.

Section 9 details the statistical properties of all centroids for several data runs along with the same properties for tracks developed by a modified ASR tracker. (See Section 10). These two data sets are compared and contrasted to highlight the features of the tracks which may be used to distinguish air targets from clutter. Also a technique is indicated which may be used to detect second time around targets on a single scan and some anomalous results, apparently generated by an unobserved jammer during the data collection, are presented.

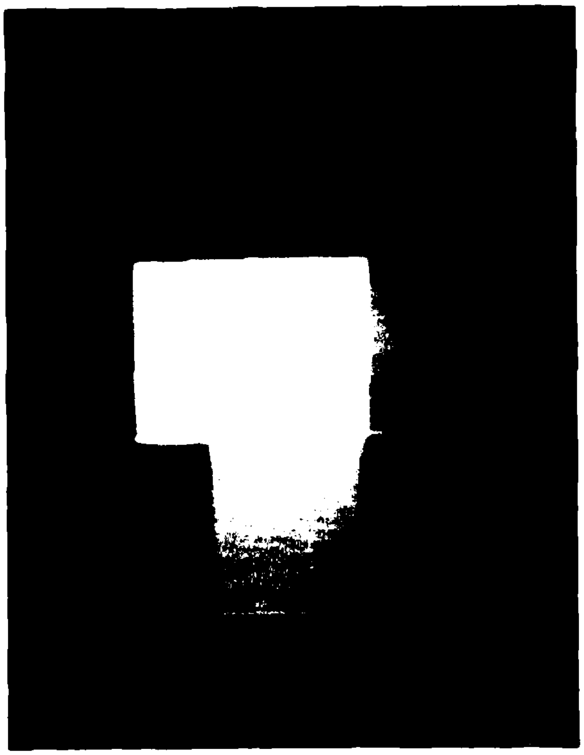
Section 10 details a simple tracker which was used as a first step in developing the amplitude and doppler properties of track centroids. These results were presented in Section 9. More interestingly, once the properties become apparent, it is feasible to use these features to discriminate between centroids to be used in tracking. Section 11 presents the resulting reduction on tracker load achieved by utilizing these centroid features during the track initiation phase of the tracking logic for the NAFEC test data. In addition, an assessment of the validity of the doppler data is made via comparison with tracker range rate data and several techniques for assuring the quality of the doppler data are indicated.

Finally, Section 12 details several theoretical efforts developed during the course of the study. In particular, a relatively simple table look-up technique is developed and evaluated for use in deriving doppler velocity. Also, an assessment is given as to the theoretical improvements which could be achieved in tracker performance via use of the doppler data in the tracking function. One potential doppler-range-bearing tracker is explored and the basis is set up for experimental verification using the NAFEC data. (This was not performed due to time constraints). Lastly, a technique is given for identifying valid doppler data based on spectral purity (i.e., the absence of JEM or propeller modulation).

The appendices contain data and information too detailed for the text. In particular, Appendix C contains a summary of all internal documents generated for this study.

Comment on Colors

During this effort, considerable use was made of color displays for presenting raw data, centroid data, and track data. Photographs of these displays are presented throughout the text as an indication of the techniques used and as examples of the impact of various processing techniques. The text attempts to describe the displays as they appear to an observer. All colors indicated were clearly observable on these displays. Unfortunately, photographic reproduction of these displays causes a distortion in the colors of the resultant prints. With different reproduction processes developing different resultant colors, Figure 4.0 presents a bar chart of all the possible colors and their associated names, to clarify the interpretation of these colors.



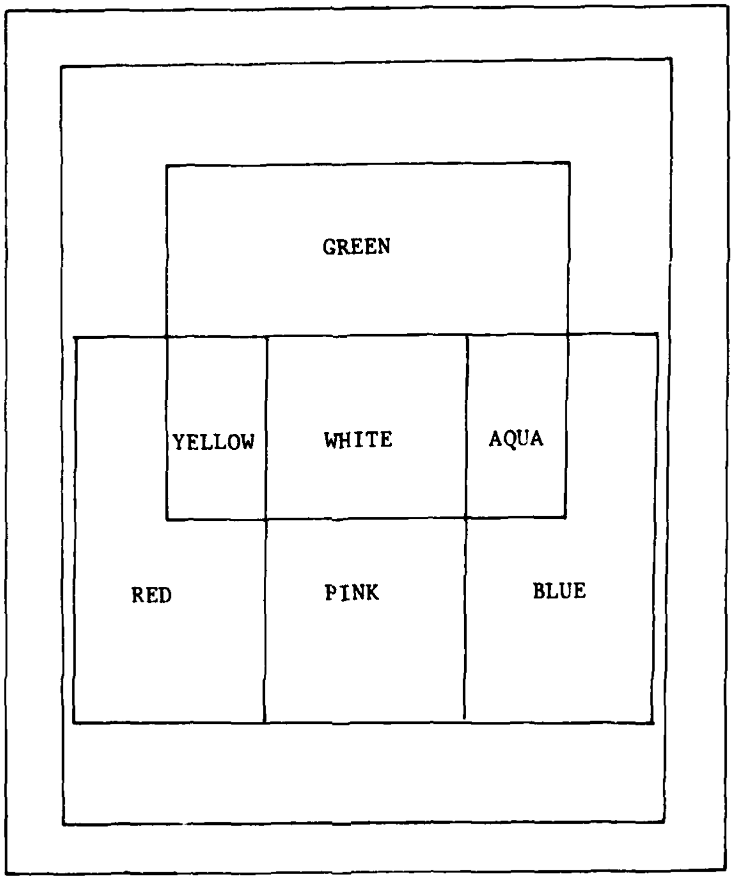


FIGURE 4.0

TEST PATTERN
COLOR CHART

5.0 BACKGROUND

With the rapid advance of high speed electronic technology it has become possible to develop devices previously only considered theoretically. Lincoln Laboratory's Moving Target Detector represents one such device developed for processing analog radar data into digital format for input to digital computer elements. The original design was developed under the auspices of the Air Force and the FAA for use with 2-D surface search radars of the Airport Surveillance (ASR) type. The design was based on the use of a coherent linear processing system with wide dynamic range. Since the ASR is not coherent nor of wide dynamic range, modifications were required. Principally this amounted to the addition of a wide dynamic range IF strip, In Phase and Quadrature detectors, and an improved STALO (to assure intra pulse coherence). As pulse to pulse coherence was not achievable within the ASRs, without considerable modification of the transmitters, the initial experiments with the prototype MTD at NAFEC used an MPD-18 radar which is similar to the ASR but has a klystron transmitter; i.e., is coherent pulse to pulse. Later, as the system proved viable, MTD was utilized with the ASR-7 at NAFEC, dropping the pulse to pulse coherence and suffering the increased second time around clutter which resulted. The penalty was increased tracker loads required to remove this additional clutter. For the NAFEC area, this penalty was nominal.

For the prototype design, following the IQ detectors was a digital Fast Fourier Transform device of the pipeline processor type designed by Lincoln Laboratory, which acted on 1/16 nautical mile samples collected over the eight preceding pulses. The 8 frequency outputs resulting from the device were each adaptively thresholded based on the computed mean values of surrounding one nautical mile range samples. Threshold crossings were outputted as hits for centroiding and tracking within a computer (IOP) located at the NAFEC facility.

Early on it was realized that the filter coefficients used in the Fast Fourier Transform had high sidelobes allowing land clutter to creep through into the high frequency filters. To suppress this effect (for the prototype), a digital MTI was placed between the detectors and the filters to reduce the land clutter returns to manageable proportions and two additional pulses were added to the processing interval to fill the delays of the MTI filter. (Later designs suppressed the filter sidelobes sufficiently that this procedure could be deleted although the prototype being slaved to the Fast Fourier Transform implementation was not able to benefit from these modifications.)

Other aids were also incorporated to suppress interference phenomena found to exist at NAFEC due to the multiplicity to nearby ASR operating on adjacent frequencies.

This, basically, was the device described in Reference 1 and was used to collect the data tapes used during this investigation. The interesting new feature of the outputs from the MTD is the presence of both doppler and amplitude information (in addition, the PRF structure was unique). Because these features are new, little use was made of these features during the initial experiments to improve track quality. However, as the experiments progressed, several algorithms were developed utilizing pure amplitude to select centroids or number of CPIs to delete centroids. At the start of this investigation, however, no systematic study had been accomplished on the use or usefulness of these new additional parameters, and this study was developed to assess the potential uses of these parameters.

6.0 APPROACH

Ideally the approach to this investigation would consist of a sequential effort starting with a statistical study of the raw MTD primitive reports and ending with the design of an optimized MTD centroiding scheme and an improved MTD tracker capable of making maximum use of these centroids. However, to speed the effort up and derive the maximum benefit for the time allowed, the effort was broken into two overlapping efforts; Raw Data Characterization and MTD Data Utilization Design. Each of these efforts may be broken into several stages as done in Figure 6-1, with the results of each stage being used to improve the designs of the previous stages. Thus the approach is iterative. In addition due to the parallel nature of these two studies, considerable exchanging of ideas and results was required, each study influencing the other. Otherwise however, the studies proceeded independently of the other, providing different viewpoints on the potential utility of the MTD data.

Basically the overall MTD Data Utilization investigation consisted of four phases; Preliminary Concept Development, Parameter Characterization, Centroid Development, and Improved Tracker Development. Although relatively easily distinguished, the phases tend to overlap; i.e., centroiding is needed to extract target and clutter characteristics which are in turn fed back into the design of the centroid algorithm. A similar feedback scheme is envisioned for the Improved Tracker Development Phase.

- Preliminary Concept Development

This phase is characterized by experimental and theoretical exploration of characteristics of the MTD output data. The experimental effort consisted of the development of interactive displays and printer listing routines to allow rapid perusal of sample MTD data. The data was first reviewed, the resulting observations consolidated, and conjectures developed which were, in turn, verified as completely as possible using the data at hand (i.e., displays, etc.). Subsequent investigations in later phases developed more fully the applicability of these preliminary conjectures.

The theoretical effort consists of a similar review of the MTD signals only on a theoretical basis. Hypotheses on this level were developed and tested as much as possible, consistent with the models on hand. (Conjectures developed during the experimental effort were also subjected to theoretical scrutiny if possible and vice versa.)

The output of this phase was an indication of possible areas for further detailed investigation during subsequent phases.

- Parameter Characteristics

Once the previous phase had indicated several possibly relevant parameters, the next phase was to develop tools for the extraction of detailed statistical characteristics of these parameters for various target types. In particular two separate and parallel approaches were pursued here, one for clutter targets and the second for air targets.

Air targets were identified manually using the PPI display developed during the first phase. The display software was modified to allow an observer to hook these targets and cause a printout of the available data in the hooked region on the selected target to be generated. After developing these printouts for several selected tracks, the analyst studied the listings to develop characteristics of the targets and identify significant features for centroiding and tracking.

To help the analyst in this effort, a parallel effort was conducted to develop the detailed characteristics of clutter targets. This effort consisted of developing the doppler and amplitude characteristics of all data obtained on a particular run. The assumption here is that the preponderance of the reports are generated by clutter returns, so that a direct characterization of clutter is obtained. Comparison of this effort with the hook procedure above highlighted significant differences between the two target types.

Additionally, the clutter study proceeded in three steps. The first step concentrated on single range bin characteristics of the clutter to ascertain statistics on the doppler characteristics of these steps. The second step will explore the range bin to range bin characteristics of clutter within a CPI. This gives details on the range extent characteristics of the clutter targets. The third step is to develop CPI to CPI characteristics of clutter returns which is related to the azimuthal characteristics of the clutter returns.

- Centroid Development

This phase is necessarily an iterative approach, as potential centroiding algorithms must be studied to evaluate their shortcomings and applicabilities to the MTD data, the results of which are used to modify and upgrade the design. These evaluations were generally statistical in nature and proceeded with and without the aid of a range and bearing tracker which utilized the centroids developed by the algorithm. Tracks were evaluated via observing the consistency of the tracks, number of false tracks, etc. The results of this evaluation was then fed back into the design of the centroiding algorithm and verified visually by comparing raw data with centroid data on an interactive display to assure valid operation.

Further, the tracker provides a means of developing a distinction between air tracks and clutter which can be used to refine the characteristics of both. The effectiveness of this distinction depends on the centroiding algorithm used as well as the tracker, so that comparison with the results of the previous phases can also be fed back into the algorithm design.

The particular approach used here concerns developing a test centroiding algorithm which generated centroids containing several relevant parameters for statistical studies and providing a base for the next phase of this effort. In particular, a large number of parameters were explored (number of Velocity Range Strength (VRS) words, max amplitude, etc.) for use in resolving air targets from each other and from clutter, as well as for developing additional information on each target; (i.e., radial velocity, spectral purity, etc.). Many of these parameters proved to be of limited usefulness and will be discarded in subsequent modifications to the algorithm.

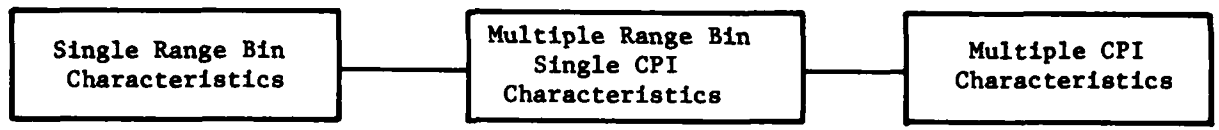
The tracker used in this study was a slightly modified ASR tracker developed for previous FAA tasks. This tracker using range and bearing data developed by the centroid algorithm, and merely retaining the other parameters for subsequent analysis, developed files for moving tracks.

- Improved Tracker Development*

Again this is an iterative problem as modifications of the tracker to allow utilization of the new information available from MTD may require, in turn, modifications of the centroiding algorithms. Thus several iterations of this phase and the previous phase may be required to develop an acceptable implementation. In particular, it is envisioned that the ASR tracker used above will be modified to make use of this additional information such as radial velocity, etc. Radial velocity tracking will be explored, as well as various techniques for promoting tracks based on doppler bin data and amplitude characteristics. Algorithms for resolving proximate tracks will also be explored, as will algorithms for utilizing doppler information in setting gate positions.

*This effort was not developed fully due to time constraints.

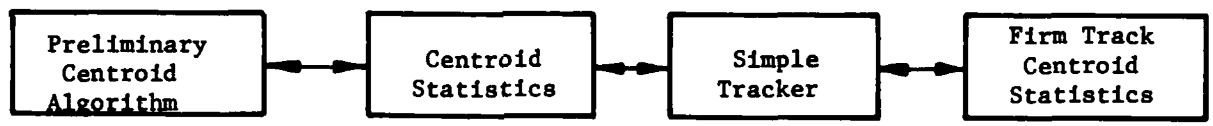
Raw Data Characterization



- Uses NAFEC MTD tapes
- Attempts to characterize the raw input data
- Primarily applies to characteristics of clutter
- Develop parameters and techniques for use in utilization design

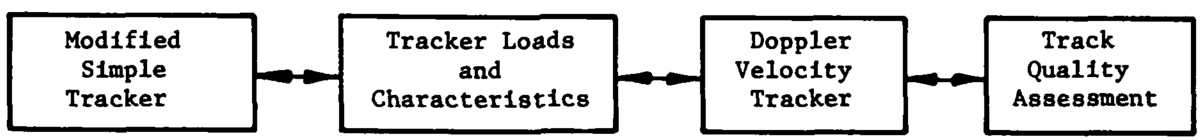
MTD Data Utilization Design

- Centroid Design



  - Evaluate centroiding techniques
  - Evaluate various parameters for distinguishing clutter and targets
  - Develop hypothesis for use in tracker design

- Tracker Design



  - Develop tracking techniques which take advantage of increased MTD data
  - Evaluate effectiveness of utilizing MTD doppler velocity in tracking algorithm

FIGURE 6.1 MTD DATA UTILIZATION STUDY OUTLINE

7.0 PRIMITIVE REPORTS

As indicated in the approach, primitive reports were to be studied more or less in parallel with centroid algorithm development via three steps; single range bin characteristics, multiple range bin characteristics, and multiple CPI characteristics. This approach allowed a sequential development of primitive report characteristics with progressively increasing complex data bases leading to the development of comprehensive centroiding algorithms which would make maximal use of the primitive report properties. Only the first step of this study was actually completed and the results of this study are the subject of the following paragraphs.

The purpose in performing these studies was threefold. Firstly, the primitive reports are the "raw" data with which the centroid algorithms the tracker, and, eventually, the controller must work. As such, properties of these data form the basis for the design of subsequent processing steps and provide a guide for developing useful discriminates. As some of these parameters are new, additional design features must be incorporated in the centroiding and tracking algorithm.

Second, the features observed in these reports are independent of any centroiding or tracking algorithm. Therefore the features developed by observing these reports are true features of the MTD generated returns and not modulated by centroiding or tracker selection logic.

Thirdly, many features worthy of study can be easily observed and verified utilizing the raw report data prior to developing the necessary software modifications and/or tools to extract these features in the complex centroiding or tracking software packages. This speeds consideration of these features and cuts the amount of labor required to confirm the validity of the feature.

7.1 Primitive Displays

Although generally a parallel development effort, the actual study of the primitive reports was begun qualitatively prior to the centroid algorithm development. This was accomplished primarily through printouts of the raw primitive reports and interactive PPI-like displays which allowed observers to pick out particular targets for detailed observation. Returns from particular regions or selected reports could be printed on command for subsequent study or to verify observations made with the display. Figure 7.1 shows a typical display used during this phase of the study. Portrayed in this photo is the actual position of each primitive report generated by the target*. Note for example that the third CPI contains only one range cell, while CPIs 1, 2 and 4 contain two range cells.

*For multiple VRS words, at a given range, the first VRS word is displayed at the actual range and bearing. The bearing of each subsequent VRS word at that range is incremented by a small amount to allow resolution of the separate returns.

Each VRS word appears on the display color coded according to the doppler bin excited by the scheme at the bottom of the photo. The display has been considerably enlarged so that one scan past the target essentially fills the display and all the returns from the target are displayed for each CPI. CPI to CPI, and range bin to range bin VRS characteristics are observable. By accumulating several scans of data on the display, scan-to-scan characteristics are also observable.

Further, the display can be interactively changed to display several other features of interest. For example, the doppler number of the bin with the maximum amplitude, the number of VRS words per range azimuth cell (using the same color scheme as Figure 7.1 except the colors now represent number of VRS words instead of doppler bin number) range extent of the target on each CPI, etc., are possible outputs of this display.

Figures 7.2 and 7.3 and Figures 7.4 and 7.5 illustrate the use of such a display in evaluating the effectiveness of a parameter (in this instance, the number of VRS words per range azimuth cell) in suppressing clutter. (Note the wedge of data is a result of the NAFEC data collection effort. Due to the data rates involved, raw data could only be collected over a finite azimuth sector.).

Figure 7.2 and 7.4 are identical to Figure 7.1 except the scale of the display has changed. In these photos, all VRS words over 20 scans have been displayed with the colors of the dots representing the doppler bin number associated with corresponding VRS word. Due to the scale, multiple VRS words in given range scale tends to obscure the actual interpretation of the colors, although in Figure 7.4 (angel returns) it is apparent that the majority of the returns are moving en masse horizontally across the photograph (to the east, as north is at the top of the display). This can be seen from the colors, as blue-green on the left of the mid point represents a positive doppler component (3), while white and yellow which dominate the right side of midline of the display indicate negative doppler (6 or 7). The fact that these colors exist uniformly about either side of the midline, implies a movement en masse of the targets.

More importantly, however, both of these figures present easily identifiable color dots for <u>all</u> the VRS words generated by the MTD. Thus weather clutter (Figure 7.2), angels (Figure 7.4) and noise (both) returns are easily observed as are target returns. Comparing these figures with the corresponding Figures 7.3 and 7.5 which display the number of VRS words per range bin using the same color scheme, presents a useful test of the effectiveness of this parameter. In particular, as single VRS range azimuth cells produce a dark blue (see Figure 2.0), these cells are visually suppressed over range azimuth cells with more VRS words (green, red, etc.). Thus it is quickly and easily observed that clutter returns are predominantly of the single VRS variety while targets (Figure 7.2 versus Figure 7.3) are generally multiple VRS words. Similarly, angel returns appear to be predominantly single VRS words.

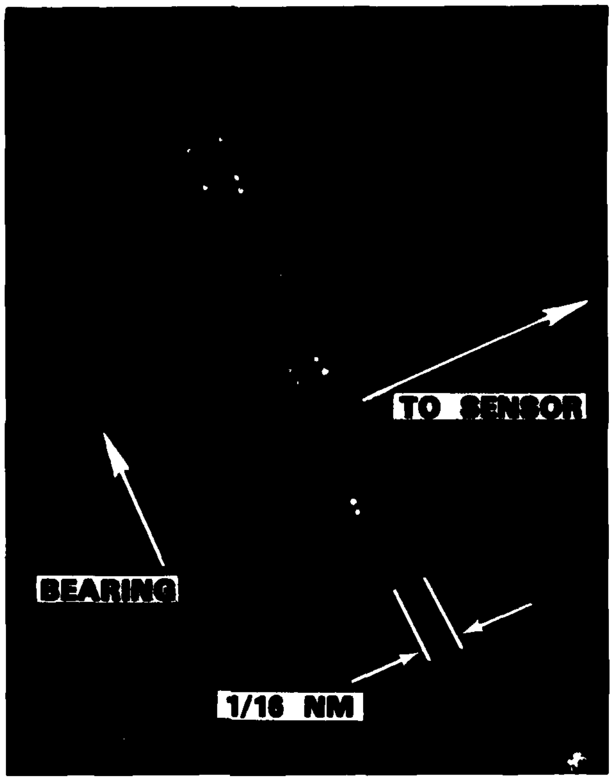


FIGURE 7.1 INDIVIDUAL VRS WORD DISPLAY

0 — TWO RED DOTS
1 — BLUE
2 — GREEN
3 — BLUE—GREEN
4 — RED
5 — RED—BLUE
6 — YELLOW (RED—GREEN)
7 — WHITE (RED—GREEN—BLUE)

INTRA CPI PROCESSING
WEATHER CLUTTER REDUCTION

20 SCAN
25 NMI RANGE RINGS

ALL DATA

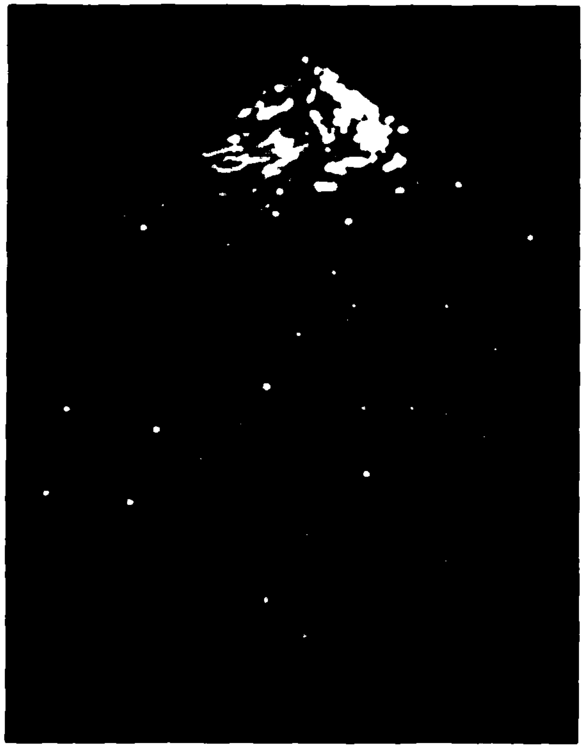
FIGURE 7.2

THRESHOLDED VRS WORD COUNT

FIGURE 7.3

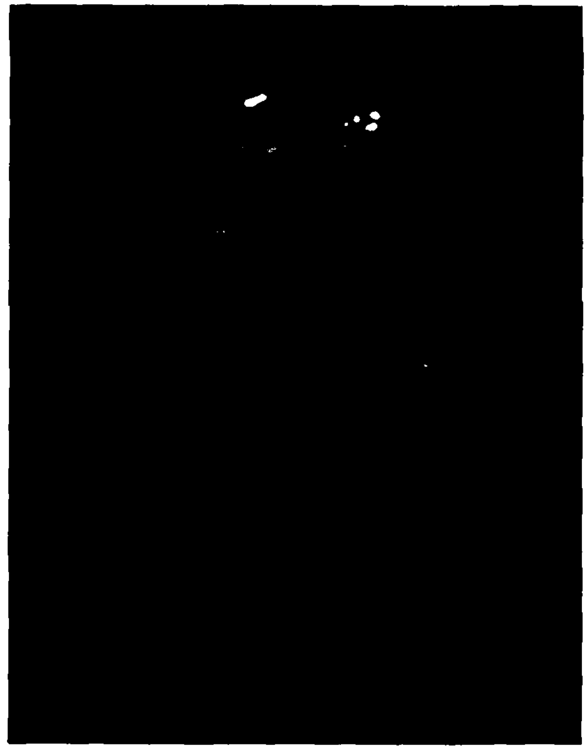
INTRA CPI PROCESSING
ANGEL CLUTTER REDUCTION

20 SCAN
25 NMI RANGE RING



ALL DATA

FIGURE 7.4



THRESHOLDED VRS WORD COUNT

FIGURE 7.5

The virtue of this technique is immediately obvious. New parameters and features may be quickly and easily given a preliminary qualitative evaluation prior to full-scale investigation. In fact, all the features and parameters discussed below were evaluated in this manner prior to subsequent study to eliminate potentially fruitless investigations.

7.2 Primitive Report Statistics

The statistics of the primitive reports were studied to develop a quantitative measure of the features for the raw MTD data. Observation of these statistics provided a basis for developing known parameters of interest, as well as those possibly overlooked by other approaches, for further study. In addition, as the statistics are for all VRS words generated during a run, the properties derived are generally to be associated with clutter, be it weather or angels. Features so developed have the additional virtue of being free of potential complications introduced when studying only centroid features which can be influenced by the centroiding algorithm.

The following describe the single range bin statistical features of three data tapes, number 12248 (weather), number 9023 (weather), and number 17321 (angels) collected at NAFEC during the prototype MTD evaluation i.e., only properties relating to data derived from single range azimuth bins are considered. In addition, statistics are evaluated as a function of range by bining results within given range intervals as follows:

Interval 0 is for ranges less than 1/2 mile.
Interval 1 is for ranges 1/2 to 1 mile.
Interval 2 is for ranges 1 to 2 miles.
Interval 3 is for ranges 2 to 4 miles.
Interval 4 is for ranges 4 to 8 miles.
Interval 5 is for ranges 8 to 16 miles.
Interval 6 is for ranges 16 to 32 miles.
Interval 7 is for ranges 32 to 47.5 miles.

These intervals have exponentially increasing range increments (powers of two), so that the areas, volumes, and detection opportunities increase exponentially for each interval. During the analysis, properties of selected parameters were developed for each range azimuth cell with a return (called a primitive target) and frequency of occurrence printouts were developed for each range interval. Tables 7.1, 7.2 and 7.3 show sample outputs for the three data tapes analyzed for the number of VRS words per primitive target (range azimuth cell) this is one of the parameters developed later on for identifying aircraft returns.

For this printout, column 1 lists the range interval over which the corresponding row of data applies. The next 8 columns are frequency of occurrence figures for the number of VRS bins per primitive target indicated at the top of the column and within the range interval indicated for the row (by column 1). The next two columns (MEAN and VARIANCE), give the associated mean and variance for the number of VRS words for primitive targets found within the corresponding range interval. The next four columns

TARGET DENSITY AS A FUNCTION OF VRS WORDS AND RANGE

VRS / RANGE	1	2	3	4	5	6	7	8	MEAN	VARIANCE	NUMBER OF TARGET	NUMBER OF VRS	NUMBER OF SNGL	NUMBER OF TWNVRS
0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	41	41	41	0
1	0.910	0.070	0.018	0.000	0.000	0.000	0.000	0.000	1.105	0.250	112	124	102	10
2	0.750	0.129	0.051	0.020	0.025	0.010	0.008	0.002	1.521	2.164	452	688	339	113
3	0.678	0.135	0.043	0.033	0.027	0.027	0.031	0.016	1.898	4.707	3147	5977	2138	1009
4	0.605	0.146	0.055	0.045	0.043	0.039	0.033	0.027	2.168	4.072	7354	15948	4462	2892
5	0.680	0.154	0.049	0.031	0.027	0.021	0.018	0.012	1.781	3.748	23358	41621	15877	7481
6	0.662	0.201	0.053	0.027	0.020	0.016	0.008	0.004	1.650	2.646	21767	35952	14432	7335
7	0.660	0.232	0.055	0.021	0.012	0.006	0.004	0.000	1.539	1.836	2704	4164	1790	914

TABLE 7.1

SINGLE RANGE BIN CHARACTERISTICS OF TARGET RETURNS FROM MTD PRIMITIVE EXTRACTION TAPE NUMBER 12248 FOR THE FIRST 2000 RECORDS (WEATHER)

TARGET DENSITY AS A FUNCTION OF VRS WORDS AND RANGE

VRS	1	2	3	4	5	6	7	8	MEAN	VARIANCE	-------NUMBER OF------- TARGET	VRS	SNGL	TWMVRS
RANGE														
0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	25	25	25	0
1	0.896	0.088	0.012	0.000	0.000	0.000	0.000	0.000	1.115	0.256	78	87	70	8
2	0.930	0.047	0.004	0.004	0.004	0.004	0.002	0.000	1.133	0.561	685	777	637	48
3	0.836	0.105	0.012	0.014	0.008	0.008	0.006	0.004	1.324	1.414	2997	3970	2509	488
4	0.643	0.146	0.057	0.041	0.039	0.029	0.025	0.014	1.951	4.732	8146	15908	5241	2905
5	0.592	0.186	0.068	0.051	0.041	0.025	0.016	0.010	1.969	4.428	13883	27352	8234	5649
6	0.551	0.215	0.068	0.047	0.039	0.031	0.023	0.018	2.100	3.201	9808	20606	5412	4396
7	0.572	0.256	0.070	0.037	0.025	0.014	0.010	0.006	1.807	3.215	7930	14341	4551	3379

TABLE 7.2

SINGLE RANGE BIN CHARACTERISTICS OF TARGET RETURNS FROM MTS PRIMITIVE EXTRACTION TAPE NUMBER 9023 FOR THE FIRST 1500 RECORDS (WEATHER)

TARGET DENSITY AS A FUNCTION OF VRS WORDS AND RANGE

VRS / RANGE	1	2	3	4	5	6	7	8	MEAN	VARIANCE	NUMBER OF TARGET	NUMBER OF VRS	NUMBER OF SNGL	NUMBER OF TWMVRS
0	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	5	5	5	0
1	0.832	0.166	0.000	0.000	0.000	0.000	0.000	0.000	1.166	0.334	36	42	30	6
2	0.756	0.240	0.002	0.000	0.000	0.000	0.000	0.000	1.246	0.502	283	353	214	69
3	0.703	0.254	0.035	0.002	0.000	0.000	0.000	0.000	1.338	0.777	1932	2587	1362	570
4	0.785	0.184	0.016	0.006	0.006	0.000	0.000	0.000	1.262	0.678	7907	9985	6214	1693
5	0.752	0.236	0.008	0.000	0.002	0.000	0.000	0.000	1.264	0.578	6767	8558	5090	1677
6	0.959	0.037	0.002	0.000	0.000	0.000	0.000	0.000	1.041	0.090	958	999	919	39
7	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	347	347	347	0

TABLE 7.3

SINGLE RANGE BIN CHARACTERISTICS OF TARGET RETURNS FROM MTD PRIMITIVE EXTRACTION TAPE NUMBER 17321 FOR THE FIRST 300 RECORDS (ANGELS) detail the actual number of VRS words (VRS), number of primitive targets (TARGET), number of single VRS word primitive targets (SNGL), and number of multiple VRS word primitive targets (TWMVRS) to allow an assessment of the significance of the results.

For example, for range interval 5 (8 to 16 nautical miles) of tape number 12248 (weather, Table 7.1), 68% of the range azimuth cells with returns had only single VRS words associated with them. Likewise, 15% consisted of 2 VRS word reports, 5% of 3 VRS words, 3% of 4 words, etc. For this range interval, on the average, 1.78 VRS words were found per primitive target, etc.

The interesting point to be observed from all these figures is that single VRS word primitive targets dominate at all ranges, and that the number of multiple VRS word primitive targets and single VRS words primitive targets are both strong functions of range. This is best illustrated in Figures 7.6, 7.7 and 7.8 which are plots of the number of single and multiple VRS word primitive targets for each range interval for each of the three tapes. Clearly from these plots, within the first 8 to 10 miles from the radar, the single word primitive targets increase as R^2, implying these returns are the result of an area phenomena, and hence proportional to the number of range azimuth cells (i.e., number of opportunities). It would appear therefore that single VRS word primitive targets are characteristics of noise and clutter (both area dependent phenomena).

Significantly, for the angel tape, Figure 7.8, the single VRS primitive target plot deviates from this R^2 hypothesis the most, indicating the distribution of the returns from the angels is also contributing, a result supported by the photograph in Figure 7.5 (and by the results in Section 9).

Multiple VRS word targets on the other hand, appear to be R^3 dependent in this same range interval, implying a volumetric dependence characteristic of point-like targets. Thus it would appear that the number of VRS words per primitive target, at least within the first 8 to 16 nautical miles can be used to indicate point targets from area or clutter targets. This hypothesis will receive more support in Section 9 when this parameter is studied for various tracks.

Next it is apparent that something happens around 8 to 16 nautical miles in all the plots, causing the numbers to maximize and then decrease thereafter as a function of range (although single VRS word primitive targets continue to dominate multiple VRS word primitive targets). This phenomena could be a consequence of several effects. The STC terminates in this region, the radar horizon is passed, and ground clutter returns subside considerably. The decrease of these numbers with range after this crossover is undoubtedly a consequence of the reduction in sensitivity of the radar with range outside the STC region. The decrease in single VRS word primitive targets further supports the contention that clutter is contributing to these returns. (Noise returns would not be range dependent).

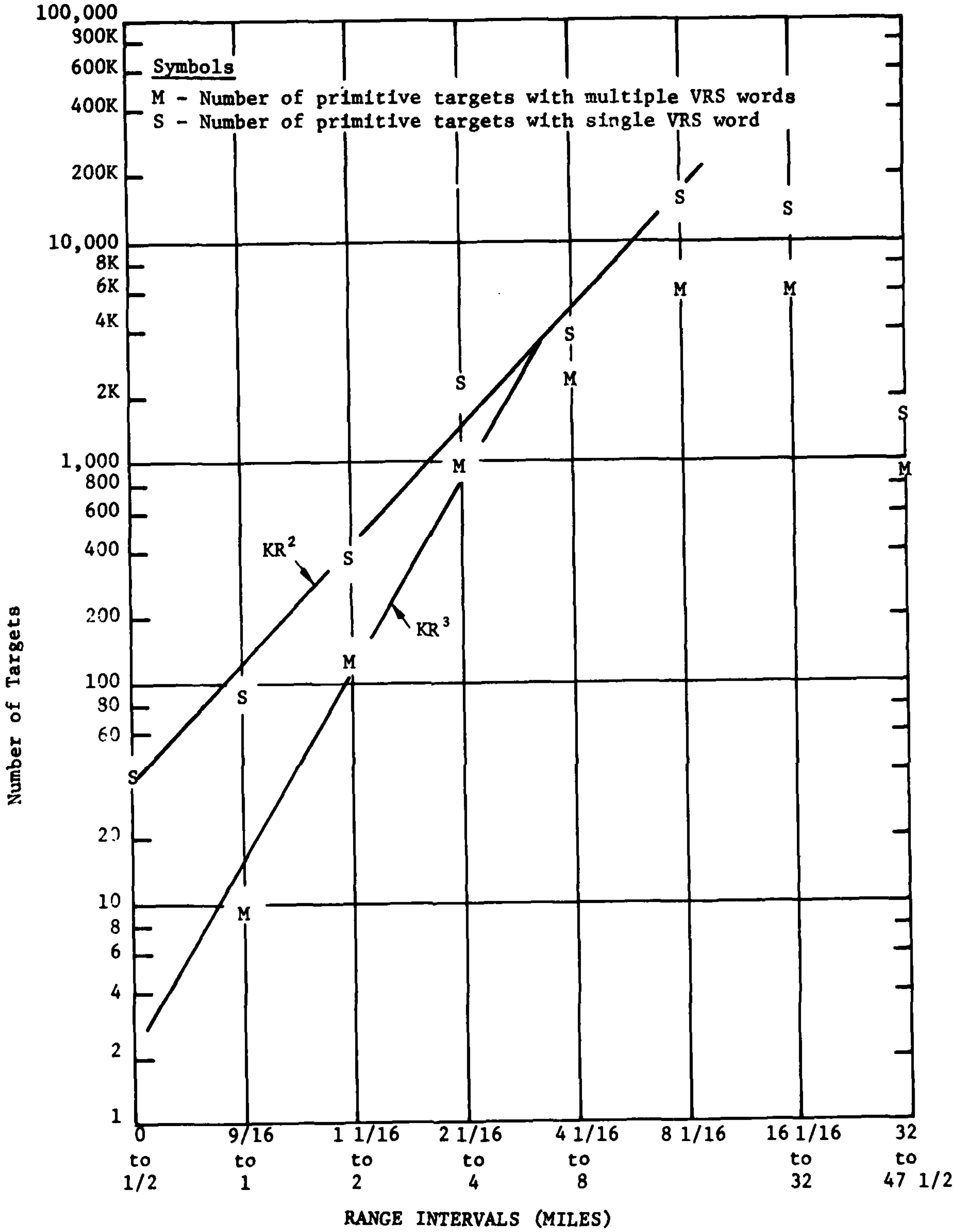


FIGURE 7.6

Plot of number of primitive targets with single VRS word, and with multiple VRS words by range interval. Data from Table 7.1, Tape Number 12248, (Weather)

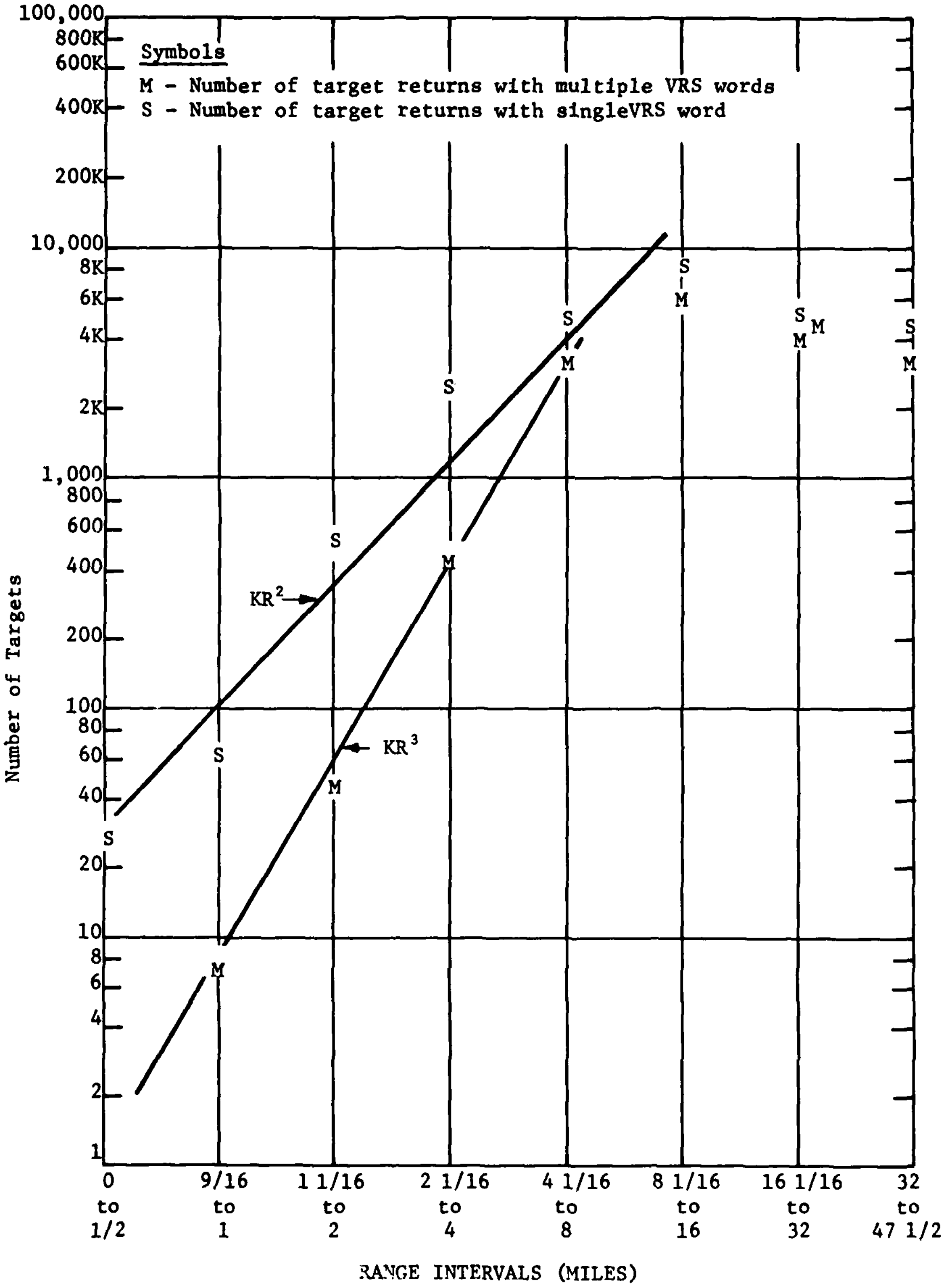


FIGURE 7.7

Plot of the number of primitive targets with single VRS word, and with multiple VRS words by range interval. Data from Table 7.2, Tape Number 9023, (Weather)

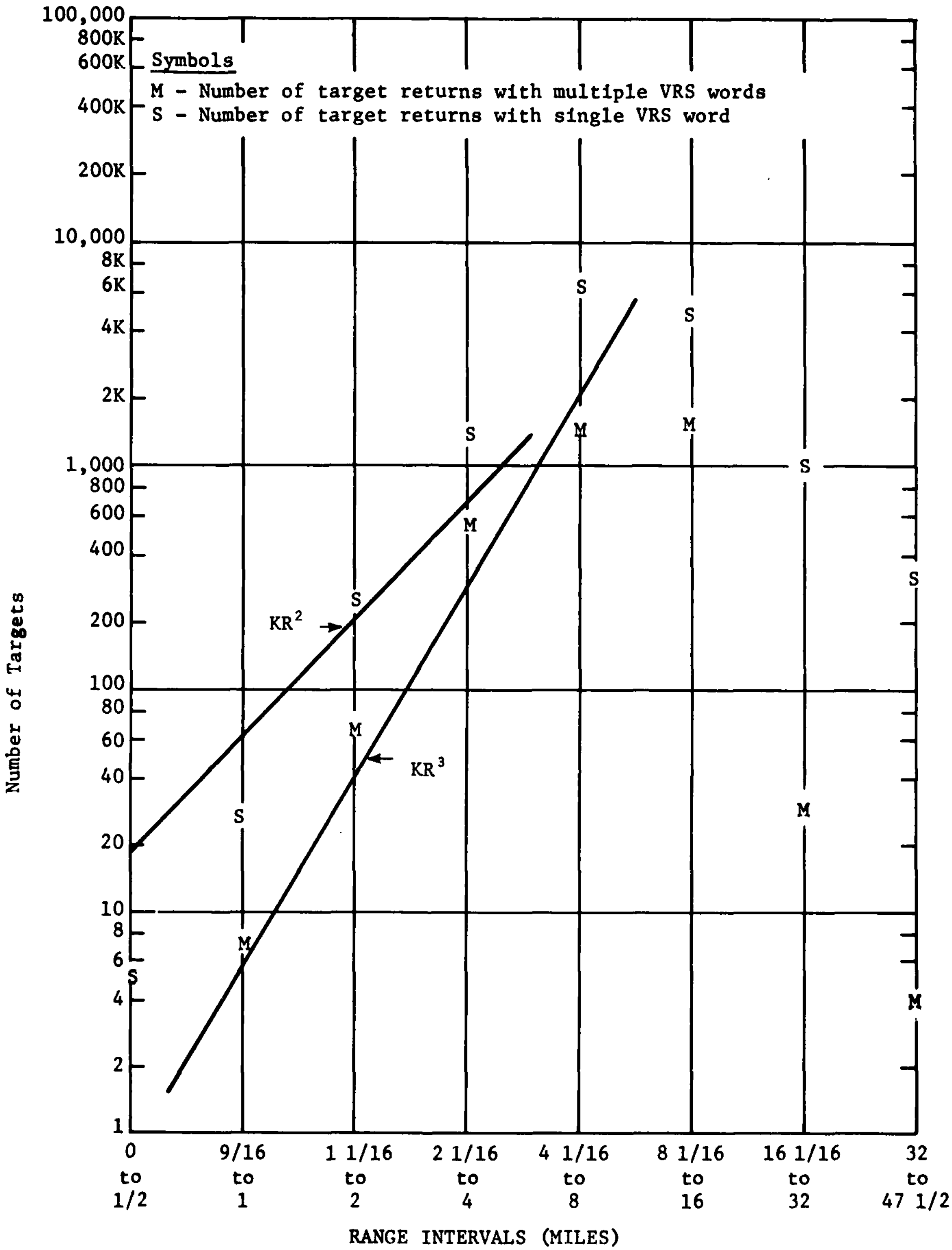


FIGURE 7.8

Plot of the number of primitive target returns with single VRS word, and with multiple VRS words by range interval. Data from Table 7.3, Tape Number 9023 (Angels)

In summary, these plots and printouts indicate the type of studies performed for the number of VRS words per range azimuth cells, the primary parameter amenable to single range bin analysis. Other parameters were also studied and discarded. Subsequent analyses begun but not completed, considered range bin to range bin, and CPI to CPI characteristic of these primitive reports.

The principal features developed by this study were subsequently incoporrporated in the centroiding algorithm and received additional study as indicated in the following sections. New parameters developed on the basis of theory or, as a consequence of additional experience, were also tested using these techniques prior to full scale implementation within the centroiding algorithm.

8.0 CENTROID DEVELOPMENT

Introduction

Centroiding is one of the principal steps in extracting useful information from sensor data for use in developing an accurate picture of the air traffic environment. During centroiding the data contained in the numerous returns from a single target are consolidated into a single report containing the essential descriptors of the returns (such as range, bearing, etc.) for use by succeeding processing stages (such as tracking, display, etc.). As a many to one conversion, the amount of information retained in the centroids is minimal and it is essential that the resulting centroid parameters developed during this process are of significance to the desired final product (i.e., effective air traffic control). Also it is essential that critical or useful information not be overlooked or discarded during this process.

In this section is described a simple, preliminary, and experimental centroiding algorithm which accomplishes these desired goals. In addition, due to the inquisitive nature of the study, the algorithm described was purposely enlarged to allow generation of additional parameters for study of the potential impact of these new parameters on subsequent processing and control functions. In particular following sections study the effectiveness of these parameters in enhancing the tracking function and in aiding in distinguishing between targets and clutter.

The algorithm to be described was implemented off-line on a Univac 1230 computer at APL, using the NAFEC primitive extract tapes as input. The resulting centroids were saved on another tape for subsequent analysis and for input to various trackers.

8.1 Algorithm Development

To assess the effectiveness of several possible centroiding techniques, a hook routine was developed in conjunction with the raw data display to allow an operator to selectively print out raw primitive reports in small regions. The operators selected apparent air tracks on the display and caused primitive reports for this track to be listed on a printer. An analyst then manually evaluated several algorithms with this data, eventually selecting the most effective technique.

In addition, as this data was representative of tracks (presumably real air targets), various parameters such as those indicated in the previous sections could be evaluated for these tracks. Comparison of these evaluations with the raw data results (section 7) allowed a gross selection process for parameters which were to be included in the algorithm output.

Note, finally, that the algorithm described below is a first pass solution. During subsequent iterations, minimally effective parameters would be deleted, new parameters may be added, more sophisticated processing may be appended, the outputs would be reduced to the minimum required to cost effectively achieve the desired goals, etc. Several improvements in this algorithm are suggested in later sections.

8.2 Algorithm Description

The basic algorithm consists of a procedure for combining together the primitive reports generated by a target to extract an estimate of the position of the target and relevant parameters descriptive of the nature of the target, if any. For this study the following rules and procedures were found effective in extracting this information*.

1) Only VRS words which were contiguous in range were used. In azimuth, due to the alternating PRF structure of the MTD, two consecutive misses in azimuth was required to terminate processing of the centroid. (This accommodates the possibility of the target falling into a blind speed for one of the PRF's.)

2) In azimuth, intermediate reports separated by ± 1/16 nautical mile were combined.

3) Adjacent range cells within a CPI were required to have the same or adjacent doppler filter excited when maximum normalized strengths are considered. If this condition was not found a flag was set (flag 8). In any case, the doppler filter with the maximum strength was retained for the CPI.

4) Adjacent CPI reports were required to have the same or adjacent doppler filter excited when maximum normalized strength was considered. If this condition was not met, a flag was set (flags 3 or 4). In any case, the filter number with the maximum strength was retained for the PRF.

5) On termination of a centroid, an amplitude weighted range and bearing was computed according to the following expressions:

---

* Note that only range and bearing information is used in selecting primitive reports for a centroid. Use was not made of doppler or amplitude information except to extract additional parameters. Later iterations may make use of this additional information.

$$\bar{r}_c = \frac{\sum_{1}^{N} r_i S_{ni}}{\sum_{1}^{N} S_{ni}} \quad ; \quad \bar{B}_c = \frac{\sum_{1}^{N} B_i S_{ni}}{\sum_{1}^{N} S_{ni}}$$

where

r_i - range of report i

S_{ni} - normalized strength of report i

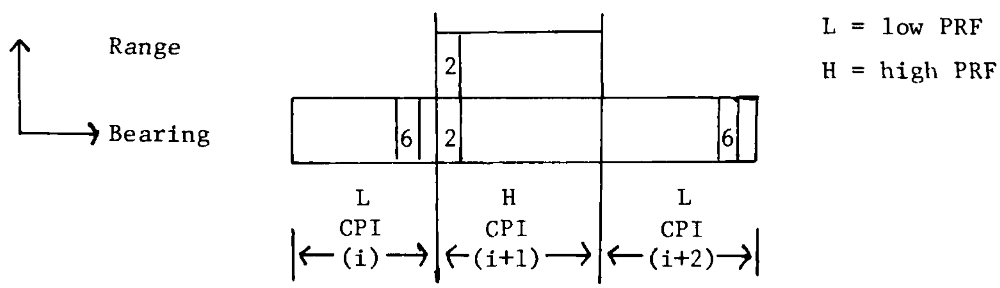
B_i - bearing of report i

$\bar{r}_c$ - estimated centroid range

$\bar{B}_c$ - estimated centroid bearing

N - number of reports

To illustrate these features and the manner in which a centroid range and bearing is obtained consider the following typical target response:



Filter 6 has the maximum Sn during CPI i and i + 2 (other filters may be excited during these CPI's but filter 6 has the maximum Sn). Filter 2 has the maximum Sn during CPI i + 1 and two contiguous range reports are obtained at that CPI. All these reports would be combined into a single centroid.

These procedures delineated which primitive reports were to be combined into the resultant centroids and extracted the minimum basic parameters required to generate a track file on potential targets. Based on the previous studies and tests as indicated above, several additional parameters were extracted using these selected primitive reports. These are:

TABLE 8.1 CENTROID FLAGS

Flag No.	Bit Field	Description
1	15	Data obtained on even PRF.
2	14	Data obtained on odd PRF.
3	13	Inconsistent alternate CPI filter number on odd PRF.
4	12	Inconsistent alternate CPI filter number on even PRF.
5	11	Amplitude inconsistence for centroids containing data from both PRF's, i.e., the maximum amplitude of one PRF is more than 3 times the maximum amplitude of the other PRF.
6	10	More than 5 CPI's of data used to form centroid.
7	9	Range extent of reports used to generate the centroids exceeds 3 consecutive range cells.
8	8	Inconsistent intra CPI doppler filter number.
9	7	Normal centroid termination.
10	6	Possible second time around target.
11	5	Data loss message encountered in raw data during generation of this centroid. Centroid processing was terminated artifically for this centroid.
12	4	This centroid began immediately after a data loss message in the raw data. Centroid may be incomplete.
13	3	Centroid processing terminated by end of sector.
14	2	Centroid begun at sector edge.
15	1	Intermediate hit file used in centroid algorithm overflow while this centroid was in process.

1) Centroid Range and Bearing ($\bar{r}_c$ and $\bar{B}_c$ above).

2) Scan PRF indicating whether 0, 1 or 2, 3 PRF pairs are transmitted.

3) Doppler filter pairs excited with the maximum Sn for the even and odd PRF's (even refers to low and odd refers to high RF s).

4) Maximum Sn for the even and odd PRF (Sn refers to normalized strength).

5) Total number of filters excited for the centroid (from all the range-azimuth cells utilized for the centroid).

6) Maximum number of filters excited on any of range-azimuth cells for the centroid. (Maximum Filter Count.)

7) Total number of range bins (range-azimuth cells combined for the centroid).

8) Maximum range extent of the primitive reports for the centroid (maximum depth of centroid in terms of number of consecutive range gates).

9) Number of CPI's (3 for example) over which primitive reports were combined to form the centroid.

10) 15 flags (0 or 1) which indicate data inconsistencies and other features.

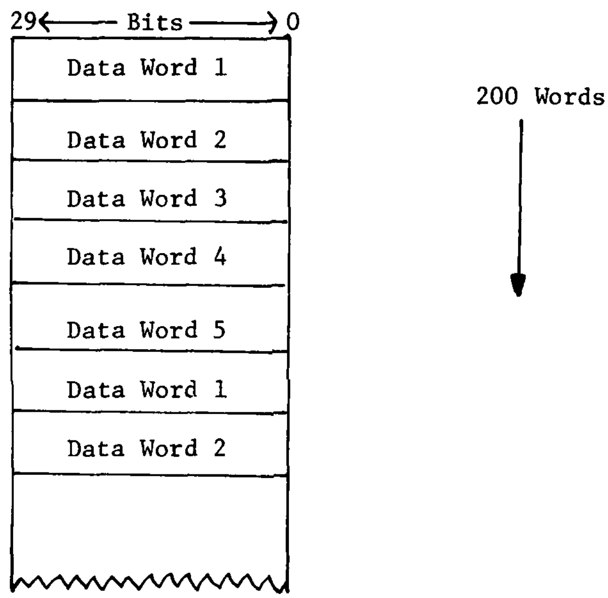
The fifteen flags indicated in 10 above are described in Table 8-1. The bit positions refer to the position of this flag in data word 4. (See below.)

These data flags are of considerable interest. For example, flag 10 is set if the primitive reports form a pattern characteristic of second time around targets (see section 9-3). Flags 3, 4, 5, and 8 indicate amplitude or doppler inconsistencies in the primitive reports combined to form the centroids. These flags form a basis for identifying potentially overlapping returns and could provide a starting point for developing more sophisticated algorithms for resolving these overlaps.

Most of the other flags represent features peculiar to the data collection or reduction scheme, indicating when set that these centroids must be used with caution due to incomplete or erroneous data resulting from processing losses. (Such as end of sector scan, beginning of sector scan, etc., i.e., end point effects.)

8.3 Output Tape Format

The Centroiding program produces a magnetic tape for further study consisting of 200 computer words for 40 centroids. Data on the tape was formatted as follows



On the tape, each data word had the following format (see Figure 8-1).

Data Word 1 - Centroid Range with LSB = 1/64 nmi (Bits 18-29), Scan Number (Bits 7-17), Total Doppler Filters Run (Bits 0-6).

Data Word 2 - Maximum Normalized Strength, Even Filter, Scaled B12 (Bits 6-29), Even Filter Number (Bits 3-5), Odd Filter Number (Bits 0-2).

Data Word 3 - Maximum Normalized Strength, Odd Filter, Scaled B12 (Bits 6-29).

Data Word 4 - Scan PRF (Bit 29), Centroid Bearing in ACP's (Bits 17-28), see Table 8-1.

Data Word 5 - Number of CPI's in Centroid (Bits 26-29), Total Number of Range Bins (Bits 21-15), Maximum Range Extent (Bits 17-20), Maximum Filter Count in any Range Bin (Bits 13-16), Last CPI of Centroid (Bits 1-12), CPI PRF (Bit 0).

FIGURE 8.1 OUTPUT TAPE FORMAT

Data Word 1

29 – 18	17 – 7	6 – 0
Range (LSB - 1/64 nmi)	Scan	Total Filters Rung

Data Word 2

29 – 6	5 – 3	2 – 0
Max. Norm. Strength Even Filters Scale 12	Even Filter #	Odd Filter #

Data Word 3

29	6 – 0
Max. Norm. Strength Odd Filters Scale 12	---

Data Word 4

29	28 – 17		15	14		1	0
SPRF	Bearing ACP's	-	Fl 1	Fl 2	.... Flags 3-14	Fl 15	-

Data Word 5

29 – 26	25 – 21	20 – 17	16 – 13	12 – 1	0
No CPI's	No Range Bins	Max. Range Extent	Max. Filter Count	Last CPI of Centroid	CPI PRF

SPRF - Scan PRF - 0,1 Lower High PRF Pattern
CPI PRF - - 0,1 Lower High PRF Pattern

9.0 CENTROIDING RESULTS

Introduction

The following paragraphs present some of the properties of the centroids developed by the centroiding algorithm discussed in Section 8. In particular, the properties of the new parameters derived from the additional MTD doppler and amplitude information are also developed both for all centroids and for those centroids associated with firm moving tracks derived by a simple range bearing tracker (see Sections 10 and 11). As a consequence of the fact that considerably more centroids were generated per scan (~66) than firm air tracks (~5), the properties developed for all centroids are deemed predominantly characteristic of clutter returns (and noise); i.e., "clutter-like". Hence, the comparisons below of the properties of the parameters for all centroids with the same parameters for the firm tracks, highlight those parameters which are most indicative of the target type. These could prove useful in developing techniques for identifying target centroids prior to tracking, allowing a reduction in tracker loads. In addition, it may be possible that the characteristic values of these parameters persist over a long time allowing scan to scan association of centroids to tracks based on those values, resolving proximate tracks and minimizing the potential interference due to clutter centroids.

The properties derived, however, are to some extent a property of the centroiding algorithm used to compute the parameter values and the tracker used to select track centroids. The algorithm and the tracker design, however, are of sufficient generality that the results can be considered characteristic of those derivable from a wide class of techniques.

9.1 Centroid Display and Verification

Preliminary results of applying the centroiding algorithm to a sample NAFEC data tape were studied in detail to verify the algorithm. Two techniques were used; manual comparison between printouts, and displays. In the manual comparison, the same raw primitive report listings for the selected targets used to develop the centroid algorithm (see Section 8) were used to compute expected centroid values and parameters for several data points for several scans. Printouts of the resultant centroids generated by the computer algorithm were then compared directly with these values to verify the algorithm.

Using the second approach, a color PPI display was generated for all centroids on a given run in a given time interval. On the display centroids were displayed in one color, say, green. On top of this display was overlaid another display in another color, say, red, of all the raw primitive reports for the corresponding input during the same time period. Due to the resolution of the display, raw reports and centroids overlapped so that it was readily apparent if tracks or data present in the raw reports was not present in the centroid data (or vice versa). Also by enlarging the display, the centroids were checked to assure that single tracks in the clear did not generate multiple centroids. Thus the operator could verify the completeness of the algorithm.

More interestingly, once the verification was complete, it was possible using these displays to present areal information on the parameters and flags associated with these centroids. In particular, Figures 9-1 through 9-9 are such displays for several parameters of interest. Each photo is a color reproduction of a PPI display of all the centroids generated by NAFEC tape 12248 for scans 556 to 605. Parameters displayed as well as the threshold values for the colors are indicated next to the photographs and in Table 9-1. Range rings are at 10 mile intervals.

Figure 9-1 shows all the centroids generated in green, a color which reproduces easily. Throughout the remaining photos, all centroids are again displayed except now each has a color associated with a value of the parameter the display is illustrating. As the color of dark blue is used to display centroids for which flags were not set, or a minimal value of a parameter which was not obtained, and as blue does not reproduce well, these centroids may appear to be missing in the photos, although they were actually observable on the display. Also, there is some additional color distortion in the reproduction process, principally causing several colors to appear as white. Figure 4.0 gives a color bar chart to assist the reader in ascertaining the color distortions developed in his copy of this report.

The technique is effective, however, in that a qualitative measure of the filtering effects achievable using thresholded parameters is developed. In particular, it appears that maximum filter count (Figure 9.4) is qualitatively the most effective parameter in suppressing clutter returns, although numbers of CPIs (Figure 9.2) are also quite effective. Other parameters can be seen to have generally lesser discriminating value.

In addition, the spational distribution of these parameters can be clearly assessed as can the "clutter likeness" or "target likeness" of the values. For example, it can be seen in Figures 9.7 to 9.9 that the amplitude and doppler inconsistency flags are almost always set in regions which in Figure 9.1 appear to be clutter dominated. On the display (or by comparison with Figure 9.1) it could be observed that in several cases these flags were set for centroids associated with moving tracks, implying that the tracker functioning for these tracks would be impaired or degraded by use of these centroids. Presumably a more sophisticated algorithm could resolve these overlapped returns and reduce the impact of including the clutter returns in a target centroid. It is apparent that these inconsistency flags provide at least a first cut basis for selecting out those centroids which will need additional processing to resolve overlaps.

Further, in Figure 9.4, the anomalies discussed in Section 9.4 are clearly visible at the 270° azimuth.

TABLE 9.1 CENTROID PHOTOGRAPH DESCRIPTIONS

Figure Number	Title	Description and Color Code
9.1	All Centroids	All centroids are displayed in green to form a reference for the following photographs. The range rings are 10 nmi/division and approximately 35 nmi range extent is displayed in the lower half disc.
9.2	Azimuth Count	Number of CPIs in the centroid Blue - 1 Green - 2 Blue-Green - 3 Red - 4 Red-Blue - 5 Yellow - 6 White - > 6
9.3	Total Range Bins	Number of Range-Azimuth cells used for centroid. Same color code as Figure 9.2.
9.4	Maximum Filter Count	The number of filters excited (number of VRS words) for the range azimuth cell with the maximum number of VRS words for the centroid. Same color code as Figure 9.2.
9.5	Maximum Range Extent	The maximum thickness of the centroid in range gates where each range gate is 1/16 nmi. Blue - 1 Green - 2 Red - 3 Red - 4 Red-Blue - 5 Yellow - 6 White - > 6

TABLE 9.1 (cont'd)

Figure Number	Title	Description and Color Code
9.6	Filters Rung	The number of primitive reports (VRS words) used for the centroid. Blue - 1 Green - 2 Blue-Green - 3 Red - 4 Red-Blue - 5 to 9 Yellow - 10 to 13 White - > 13
9.7	Flags 3 and 4	Inconsistent Inter-CPI flags 1 (1) for flag 3 (4) indicates inconsistent inter-CPI filter numbers for the even (odd) PRFs for the centroid. Flag 3 Flag 4 0 0 Blue 1 0 Green 0 1 Red-Blue 1 1 Yellow
9.8	Flag 8	*Inconsistent intra-CPI doppler filter numbers.* Flag 8 0 Blue Not Set 1 Red Set
9.9	Flag 5	Amplitude Inconsistency (Ratio > 3) when Flag 5 = 1 Blue - Flag 5 - Not Set Red - Flag 5 - Set

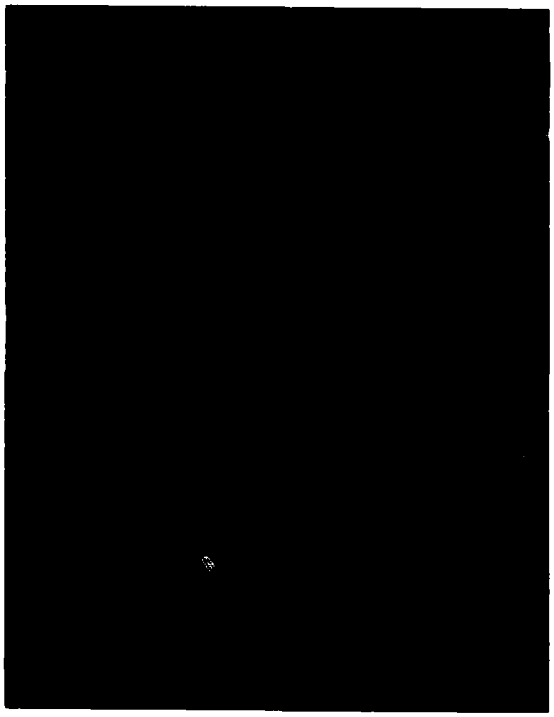


Figure 9.1

All Centroids
50 scans

Color	Value	No.
Green	All	2880

Figure 9.2
Azimuth Count

Color	Value	No.
Blue	1	2303
Green	2	338
Blue-Green	3	151
Red	4	60
Red-Blue	5	22
Yellow	6	4
White	> 6	2

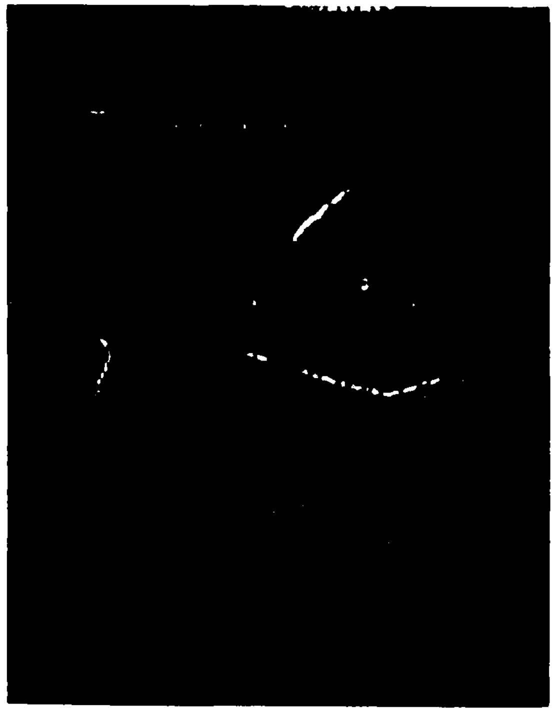


Figure 9.3 Total Range Bins

Color	Value	No.
Blue	1	2068
Green	2	448
Blue-Green	3	110
Red	4	77
Red-Blue	5	47
Yellow	6	63
White	>6	67

Figure 9.4 Maximum Filter Count

Color	Value	No.
Blue	1	2269
Green	2	355
Blue Green	3	57
Red	4	35
Red-Blue	5	46
Yellow	6	52
White	7 or 8	66

Figure 9.5 Maximum Range Extent

Color	Value	No.
Blue	1	2315
Green	2	533
Red	3	32
Red	4	0
Red-Blue	5	0
Yellow	6	0
White	>6	0

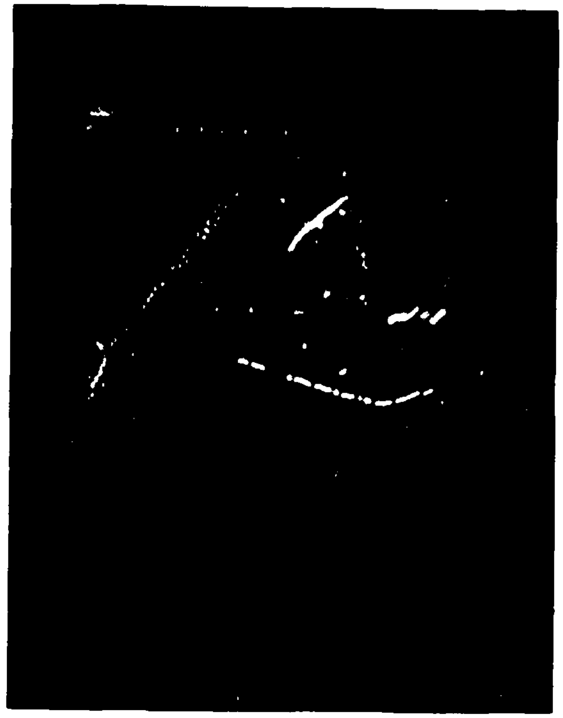


Figure 9.6 Filters Rung

Color	Value	No.
Blue	1	1898
Green	2	455
Blue Green	3	128
Red	4	86
Red-Blue	5→9	135
Yellow	10→13	45
White	>13	133

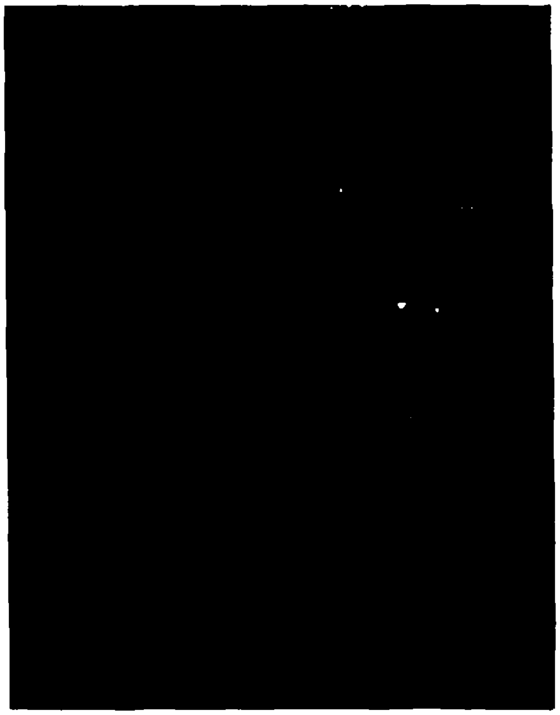


Figure 9.7
Flags 3 and 4
(Inconsistent - Inter-CPI)

Flag 3	Flag 4	Color	No.
0	0	Blue	2852
1	0	Green	15
0	1	Red-Blue	10
1	1	Yellow	3

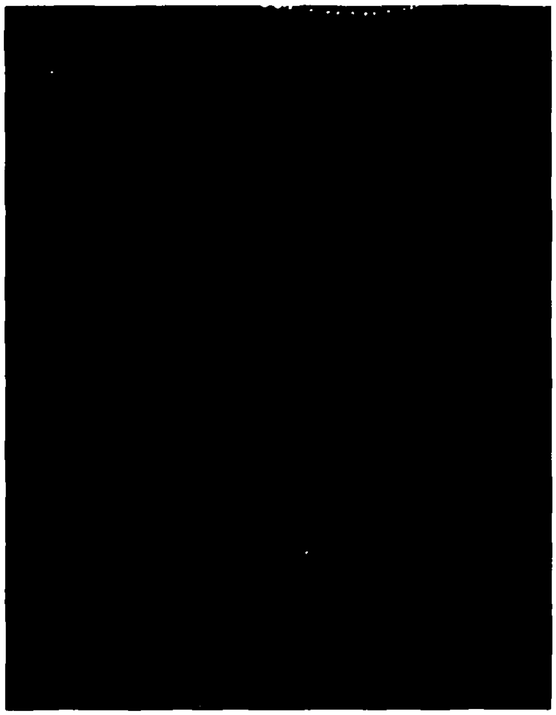


Figure 9.8
Flag 8
(Inconsistent - Intra-CPI)

Flag 8	Color	No.
0	Blue	2861
1	Red	19

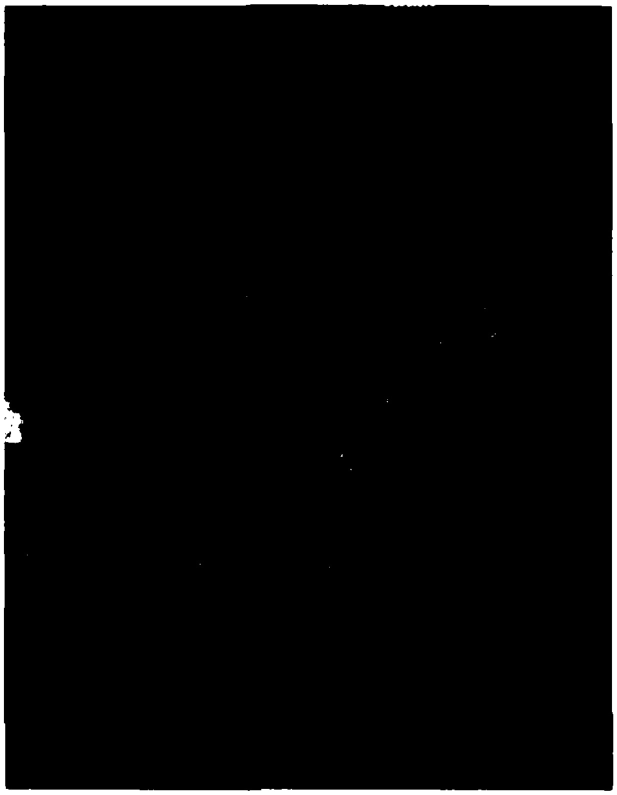


Figure 9.9
Flag 5
(Amplitude Inconsistency)

Flag 5	Color	No.
0	Blue	2812
1	Red	68

9.2 Centroid Statistics

The previous section presented a qualitative and areal description of the properties of the centroids generated using the NAFEC MTD data. The following paragraph addresses the quantitative nature of these centroids from a statistical point of view. Global statistical descriptions of the parameters are developed for the seven runs listed in Table 9.2, while Table 9.3 gives the size of the data base developed by using the results for all runs. Note that run 7 consists mainly of angel returns while the other runs (1-6) are labeled as weather in the NAFEC log books. Thus the descriptions of these two categories of runs are slightly different. Also included in the results below are the statistical descriptions of these same parameters developed for those centroids which resulted in the generation of a firm track (using the tracker described in Section 10).

As a consequence of the fact that many of the parameters had a considerable range of possible values, it was necessary to bin the results to achieve a compactness of the output to ease their study, and to enhance the stability of the results due to the sparseness of data points when overbining occurs. In particular, the following bining procedure was used for the parameters:

1. Range - the centroid range $\overline{r}_c$ was placed into 8 bins as follows:

$$0 < \overline{r}_c < 0.5 \text{ nmi}$$

$$0.5 \times 2^n \leq r_c \leq 0.5 \times 2^{n+1} \quad ; \quad n = 0, 1, 2, 3, 4, 5$$

$$32 \text{ nmi} \leq \overline{r}_c$$

in order to conform to the range bins used in Section 7 and allow direct comparison of the results.

2. Maximum Normalized Strength - MAX SN was placed into 65 bins as follows:

$$0 < \text{MAX SN} \leq 8$$

$$8n \leq \text{MAX SN} \leq 8(n+1) \quad ; \quad n=1, \ldots, 63$$

$$512 \leq \text{MAX SN}$$

3. Number of Filters Rung - the total number of primitive reports that went into making up the centroid (number of VRS words) was placed into 41 bins extending between 1 and 40 and greater than 40.

TABLE 9.2 MTD DATA RUN DESIGNATIONS

Run No.	Tape No.	Scans	Date
1	12248	556-884	8/6/75
2	12248	909-1008	"
3	12248	1009-1158	"
4	9023	1324-1597	"
5	9023	1598-1658	"
6	9023	2035-2195	"
7	17321	28-165	No Date

TABLE 9.3 STATISTICAL DATA BASE PARAMETERS

Total run time	1.58 hours
Total Number of Centroids	79,860
Average Number of Centroids per Scan	66.1
Total Firm Track Centroids	7750
Total Number of Scans	1208

4. Number of Azimuths - the number of CPIs for which data was obtained for the centroid was placed into 8 bins extending from 1 through 7 and greater than 7. If the radar is blind to one of the prf's the number of azimuths is not incremented during the CPI corresponding to the blind prf.

5. Total Range Bins - the number of range-azimuth cells for which data was obtained for the centroid. This number was placed in 11 bins between 1 and 10 and greater than 10.

6. Frequency of even (low prf) filter - the frequency of occurrence for each of the doppler filters for all the centroids. Only the filter number with maximum normalized strength on the low prf is used for these statistics.

7. Frequency of odd (high prf) filter - same as above for the high prf filters.

8. Maximum Filter Count - the largest number of filters excited in a range-azimuth cell for the centroid ($1 \leq MFC \leq 8$).

9. Range Extent - maximum depth of the centroid in range gates ($1 \leq MRE$) where each range gate corresponds to 1/16 nmi.

10. Ratio of max SN to min SN - for centroids with low and high prf data and no inconsistency flags this is the ratio of the maximum normalized strength to the minimum normalized strength. Both strength values are obtained from low and high prf data.

11. Ratio Filters Rung to Total Range Bins - the number of VRS words (primitive reports) in the centroid divided by the number of range-azimuth cells excited for the centroid.

12. FLAGS (FLAG SET = 1, FLAG NOT SET = 0)

    a. Flag 1 is set when data is obtained on low (even) prf.

    b. Flag 2 is set when data is obtained on high (odd) prf.

    c. Flag 3 is set on alternate CPI inconsistency on the low prf. This means that the filter number with max SN or CPI n does not agree with the corresponding filter number on CPI n + 2. A difference in filter number of ±1 is tolerated and the modulo 8 arithmetic for the filter numbers has been taken into consideration.

12. d. Flag 4 - the same consistency check as above for the high prf data.

 e. Flag 8 is set when the filter number with max SN on CPI n at range r does not agree with the corresponding filter number on the same CPI at range r + one. This is classified as an intra-CPI inconsistency and a difference in filter of ±1 is tolerated (flag will not be set if difference is ±1 filter number).

 f. Flag 10 is set when the centroid displays characteristics of second time around targets. These characteristics are described in Section 8.3.

13. Average Centroids per Scan - the total number of centroids divided by the number of scans yields this quantity.

Detailed results for two runs (1 and 2) are given in Appendix A. These results, however, are so extensive that a distilled version of the significant results is contained in Tables 9.4 to 9.7. Both firm track (Tables 9.6 and 9.7) and all centroid (i.e., clutter, Tables 9.4 and 9.5) results are presented. It is these tables which are contrasted and compared below.

Table 9.4 presents all centroid data for Run 1-7 and Table 9.6 presents Firm Track only centroid data for these runs. The numbers indicate that for Runs 1-6 there is approximately a 10 to 1 reduction from all centroids to FT centroids (69,450 centroids, 7629 FT centroids). For the angel clutter run approximately a 100 to 1 reduction is taking place (10,410 centroids, 121 FT centroids). Tables 9.1 and 9.3 present the results where Runs 1-3 and Runs 4-6 have been averaged into two combined runs. Run 7 is left alone since it is a distinctly different run.

For all centroids a numerical value of 1 for Number of Azimuths, Maximum Filter Count and Range Extent is most likely. Percentages vary between 75 and 80% for a numerical value equal to 1 for these quantities in Runs 1-6. In Run 7 a single CPI represents 63.6% of the centroids.

Most importantly, however, is the appearance of major shifts in the frequency of occurrence of values of several parameters when all centroid results compared to the firm track only results. In particular, the maximum filter count distribution, the number of CPIs distribution, the maximum range extent distribution are all significantly shifted towards higher values for the firm track centroids. These shifts are clearly visible when comparing the results for Runs 1 through 6. Run 7, the angel tape, had no clearly defined moving targets, so the number of firm track centroids generated by the tracker algorithm is quite low (121). As can be seen in comparing the firm track statistics with the statistics for all centroids for this run, they are essentially the same indicating the firm tracks generated were clutter tracks.

TABLE 9.4 All Centroids - Sample Statistics Run Averages

NUMBER OF AZIMUTHS (CPIs)

NO. OF CPIs	1, 2 & 3 %	4, 5 & 6 %	7 %
1	78.7	75.7	63.6
2	11.9	12.8	26.3
3	5.4	6.0	7.5
4	2.7	3.5	2.0
5	1.0	1.5	0.3
6	0.3	0.4	0.0
7	0.0	0.1	0.0
> 7	0.0	0.0	0.0
Total Centroids	34445	35005	10410

Total Centroids - ALL: 79860

MAXIMUM FILTER COUNT

FILTER COUNT	%	%	%
1	78.7	76.1	73.9
2	12.6	11.7	23.1
3	3.0	2.8	1.6
4	1.8	2.2	0.5
5	1.7	2.1	0.6
6	1.5	1.8	0.0
7	1.4	1.7	0.0
8	1.2	1.6	0.0

RANGE EXTENT

RANGE EXTENT (Range Cells)	%	%	%
1	79.3	78.9	75.1
2	19.7	19.5	24.3
3	1.1	1.7	0.4
4	0.0	0.0	0.0
Centroids per Scan	59.8	70.9	76.0

TABLE 9.5 ALL Centroids - Sample Statistics

Number of CPIs

CPIs	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	15722	78.6	4820	76.9	6566	80.1	10126	76.4	1878	73.8	14482	75.3	6627	63.6
2	2416	12.0	763	12.1	931	11.3	1475	11.1	276	10.8	2714	14.1	2738	26.3
3	1070	5.3	386	6.1	388	4.6	879	6.6	207	8.1	1017	5.3	791	7.5
4	546	2.6	176	2.8	202	2.4	516	3.9	124	4.8	586	3.0	211	2.0
5	166	0.8	89	1.4	83	1.0	195	1.4	41	1.5	291	1.5	36	0.3
6	51	0.3	30	0.4	16	0.1	41	0.3	17	0.6	87	0.4	7	0.0
7	10	0.0	3	0.0	2	0.0	13	0.0	1	0.0	28	0.1	0	0.0
> 7	7	0.0	2	0.0	0	0.0	1	0.0	1	0.0	8	0.0	0	0.0
Total Centroids	19988		6269		8188		13246		2545		19214		10410	

MAXIMUM FILTER COUNT

Filter Count	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	15557	77.8	4755	75.8	6123	74.8	9460	71.4	1757	69.0	15421	80.3	7693	73.9
2	2357	11.8	823	13.1	1169	14.3	1705	12.8	302	11.8	2073	10.8	2417	23.1
3	557	2.8	215	3.4	255	3.0	544	4.0	106	4.1	334	1.6	171	1.6
4	328	1.6	137	2.1	160	1.9	393	2.9	115	4.5	252	1.3	55	0.5
5	322	1.5	114	1.8	152	1.8	356	2.6	115	4.5	267	1.4	71	0.6
6	320	1.5	94	1.4	116	1.4	305	2.3	64	2.5	265	1.4	3	0.0
7	283	1.4	80	1.3	103	1.3	273	2.0	58	2.3	272	1.4	0	0.0
8	264	1.3	51	0.8	110	1.3	210	1.5	28	1.0	330	1.6	0	0.0

RANGE EXTENT

Range Extent	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	15901	79.5	4916	78.4	6481	79.1	10162	76.6	1862	73.1	15578	81.0	7826	75.1
2	3877	19.4	1269	20.1	1633	19.9	2865	21.6	634	24.9	3312	17.1	2532	24.3
3	210	1.0	81	1.3	73	0.9	216	1.6	46	1.8	317	1.6	49	0.4
4	0	0.0	3	0.0	1	0.0	3	0.0	3	0.0	7	0.0	3	0.0

TABLE 9.6 Firm Track Centroids On`v ample Statistics Run A.erage,

Number of CPI's

AZIMUTH

	1, 2 & 3	4, 5 & 6	7
AZIMUTH	%	%	%
1	15.2	14.3	63.6
2	21.8	22.2	32.1
3	33.2	29.9	4.1
4	19.7	21.2	0.0
5	7.5	9.3	0.0
6	2.2	2.4	0.0
7	0.3	0.6	0.0
> 7	0.1	0.1	0.0
Total Centroids	3485	4144	121

Total Centroids - ALL 7750

MAXIMUM FILTER COUNT

Filter Count	%	%	%
1	13.7	13.5	86.8
2	24.0	19.6	13.1
3	14.0	13.3	0.0
4	10.2	11.4	0.0
5	9.0	12.2	0.0
6	9.8	10.7	0.0
7	9.7	9.7	0.0
8	9.5	9.6	0.0

RANGE EXTENT

Range Extent (Range Cells)	%	%	%
1	21.0	22.7	69.4
2	71.4	67.3	28.9
3	7.6	9.7	1.6
4	0.0	0.3	0.0

TABLE 9.7 Firm Track Centroids Only - Sample Statistics

Number of Azimuths

AZIMUTHS	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	279	14.4	121	15.9	129	16.3	249	12.1	49	10.9	293	17.8	77	63.6
2	432	22.3	169	22.3	159	20.1	483	23.5	99	22.0	338	20.5	39	32.1
3	659	34.0	243	32.0	255	32.3	660	32.1	148	32.9	432	26.3	5	4.1
4	406	20.9	123	16.1	157	19.8	436	21.3	102	22.6	342	20.8	0	0.0
5	116	5.9	72	9.5	74	9.3	177	8.6	34	7.5	175	10.6	0	0.0
6	34	1.8	26	3.4	15	1.9	37	1.8	16	3.5	45	2.6	0	0.0
7	9	0.4	2	0.3	1	0.1	7	0.3	1	0.1	15	0.9	0	0.0
> 7	3	0.1	1	0.1	0	0.0	0	0.0	1	0.1	4	0.1	0	0.0
Total Centroids	1938		757		790		2049		450		1645		121	

MAXIMUM FILTER COUNT

Filter Count	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	274	14.1	96	12.6	108	13.6	241	11.8	49	10.9	268	16.3	105	86.8
2	402	20.6	253	33.4	182	23.0	433	21.1	87	19.3	292	17.8	16	13.1
3	276	14.1	122	16.0	91	11.5	290	14.1	59	13.0	201	12.1	0	0.0
4	213	10.9	67	8.8	76	9.5	239	11.6	71	15.8	161	9.8	0	0.0
5	188	9.6	53	7.0	74	9.3	242	11.8	91	20.1	173	10.5	0	0.0
6	204	10.5	59	7.8	77	9.6	232	11.3	42	9.3	171	10.4	0	0.0
7	190	9.8	69	9.0	79	10.0	200	9.8	35	7.8	169	10.3	0	0.0
8	191	9.8	38	5.0	103	13.0	172	8.4	16	3.5	210	12.8	0	0.0

RANGE EXTENT

Range Extent	Run #1 Number of Centroids	Run #1 %	Run #2 Number of Centroids	Run #2 %	Run #3 Number of Centroids	Run #3 %	Run #4 Number of Centroids	Run #4 %	Run #5 Number of Centroids	Run #5 %	Run #6 Number of Centroids	Run #6 %	Run #7 Number of Centroids	Run #7 %
1	414	21.3	151	19.9	167	21.1	428	20.9	80	17.8	434	26.4	84	69.4
2	1381	71.3	539	71.1	567	71.8	1446	70.5	333	74.0	1010	61.4	35	28.9
3	143	7.4	66	8.6	56	7.0	172	8.4	35	7.8	194	11.8	2	1.6
4	0	0.0	1	0.1	0	0.0	3	0.1	2	0.4	7	0.4	0	0.0

It is these shifts and the observations in Section 9.2 that lead one to attribute certain values of the parameters to clutter and hence designate centroids having parameters within this range as "target-like" and all others as "clutter-like". Use will be made of these distinctions in Section 11.

Finally, note that the distinctions are not complete; i.e., approximately 15% of the firm track centroids fall into the clutter-like category. As these firm track centroids are "clutter-like", this implies that <u>all</u> centroids must be passed to the tracker.

9.3 Second Time Around Targets with MTD

Introduction

The MTD centroider described in Section 8 flags possible second time around targets on an intra-scan basis. These targets have actual ranges which are greater than the unambiguous range of at least one of the MTD pulse repetition frequencies. In order to assess the effectiveness of this flag procedure, two second time around targets were identified via these flags and studied in detail via the hook and printout procedure described in Section 8. These targets are from Run 2, tape 12248. The actual ranges of these two targets extended from 71 to 74 nmi and from 80 to 96 nmi, respectively. The conclusions which have been drawn are the following:

1. For target #1, approximately 50% of its centroids were correctly flagged as second time around targets on an intra-scan basis. The other 50% of its centroids are not flagged since they are the result of single CPIs* The latter are not flagged in this procedure since most false alarms fall into the single CPI category.

2. For target #2, approximately 33% of its centroids were correctly flagged as second time around targets. The remaining 67% of its centroids are not flagged and are again single CPI responses.

3. With the track acquisition logic for the ASR tracker as described in Section 10, these second time around targets will never advance past the tentative track state if their display range is < 32 nmi. This latter fact is due to the prf incremental change from scan to scan and the window sizes of the ASR tracker.

4. If single CPI responses and second time around flagged results are ruled out as new tentative tracks then this rule will not allow second time around target reports to initiate any tracks (even new tentative tracks). This will help to reduce the track load, and help in regulating false alarms due to the exclusion of second time around tracks on the controller's display.

5. Since the possibility exists for identifying second time around targets, it is easy to envision tracking these targets by range correcting the MTD centroids and inputting these centroids to the ASR tracker.

---

*Undoubtedly the single CPI response is due to the weakness of the return brought about by the extreme range of the target.

Discussion of Theory

The MTD transmitter uses four prf whose values are

EVEN $PRF_1 = 1113.1$ Hz $\equiv 1$ ODD $PRF_3 = 1120.8$ Hz $\equiv 1 + \Delta$

SCANS $PRF_2 = 1367.7$ Hz $\equiv h$ SCANS $PRF_4 = 1379.4$ Hz $\equiv h + \Delta$

As a consequence of the mechanics of the radar, an aircraft at range R is reported or displayed at range R_i for the i^{th} prf where

$$R_i = R \text{ modulo } \frac{C}{2 \cdot prf_i} \qquad (C = \text{speed of light})$$

With the four prf values above, R_i becomes

EVEN R_1 = R modulo 72.76 nmi ODD R_3 = R modulo 72.26 nmi

SCANS R_2 = R modulo 59.22 nmi SCANS R_4 = R modulo 58.72 nmi

PRFs 1 and h alternate on even scans and prfs $1 + \Delta$ and $h + \Delta$ alternate on odd scans. As a consequence of these transmissions, second time around targets give rise to the characteristic responses shown in Figure 9.10 during the time on target (intra-scan). Similarly, the scan to scan characteristics of range ambiguous targets are shown in Figure 9.11.

As can be noted from Figure 9.10 on even scans, for actual target ranges between 59.22 and 72.76 nmi, only high prf target responses are obtained. These responses also occur at a displayed range of less than 13.54 nmi. In the present mechanization, flag 10 is activated when two high prf responses are obtained with a gap in between. For actual target ranges between 72.76 and 106.72 nmi a complementary situation exists between the high and low prf detections whereby the high prf detections occur at a range 13.54 nmi greater than the low prf detections. In the present mechanization, flag 10 is actuated when two lows and a complementary high are obtained, or two highs and a complementary low. For actual target ranges between 106.72 and 118.44 only low responses are obtained. This situation is presently not flagged in the centroid procedure.

The scan to scan characteristics of range ambiguous targets are shown in Figure 9.11. The dashed line represents the range behavior of a non-ambiguous target traveling at $\dot{R}$ = + 600, 0 and - 600 knots. The solid lines represent the range behavior of a second time around target with the same $\dot{R}$ values. Note the characteristic jumps between successive scans which are a function of the prf change and the target range motion. Illustrations

Figure 9.10 Intra-Scan Responses of Range Ambiguous Targets

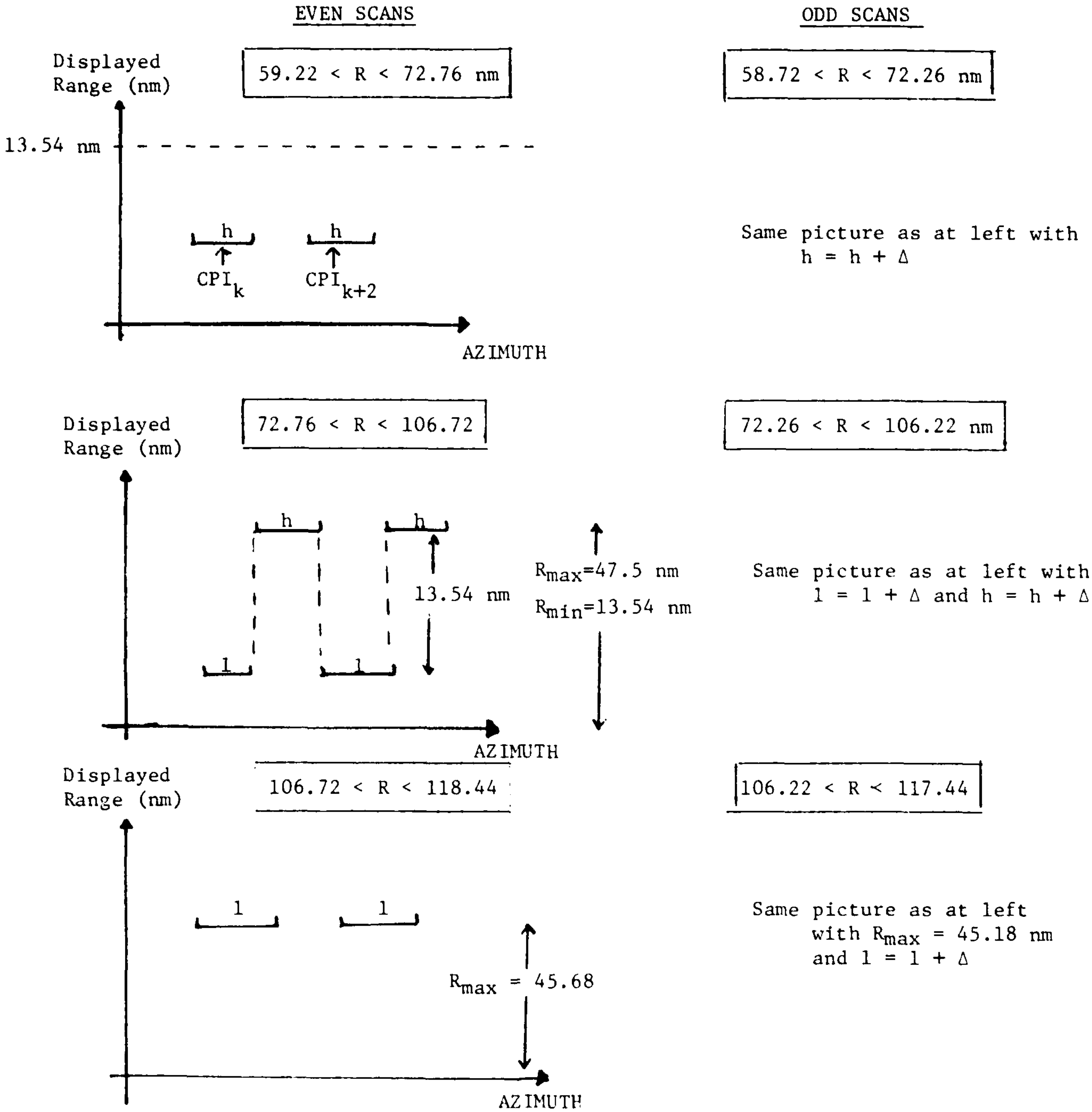
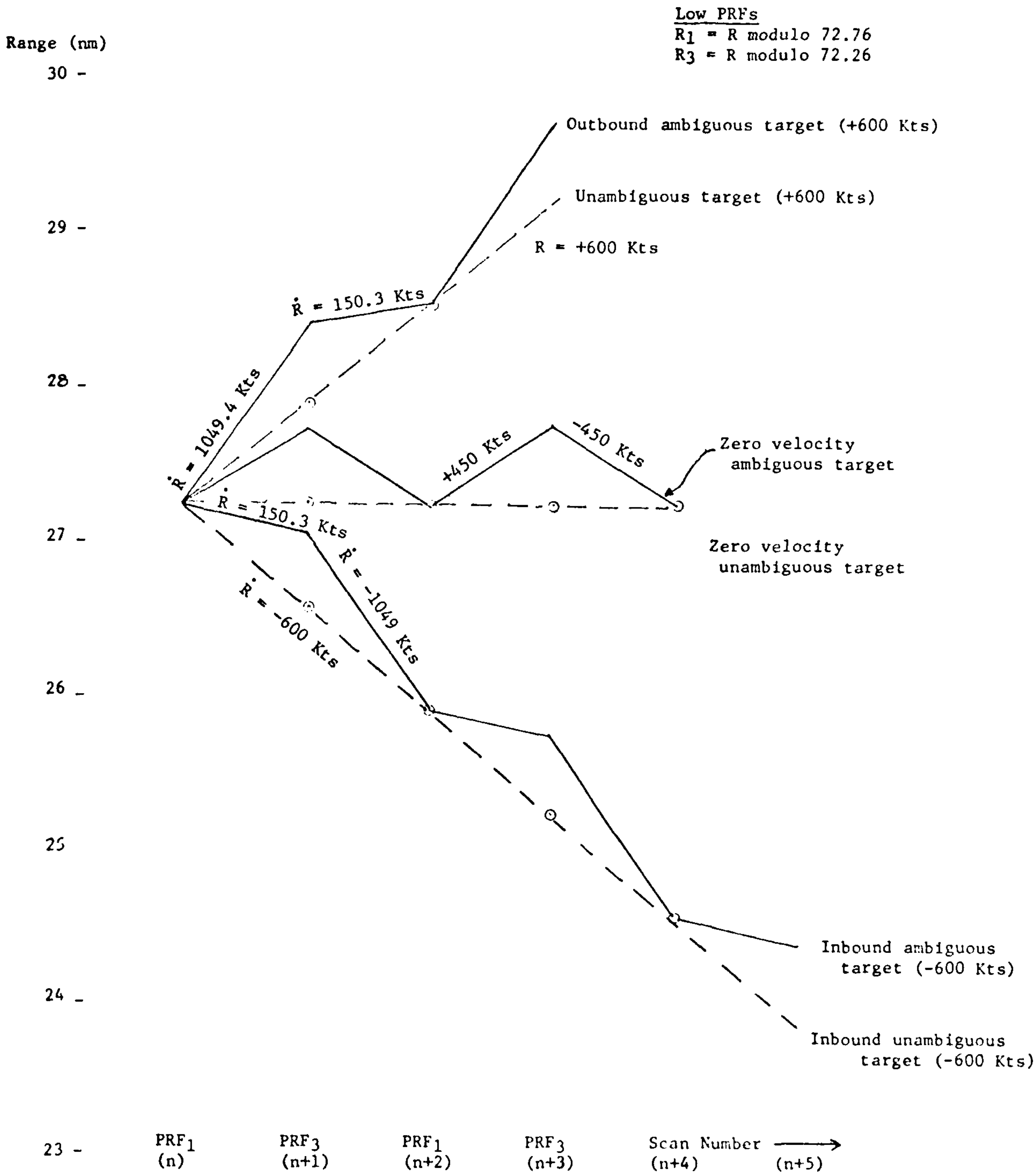


Figure 9.11 Scan to Scan Characteristics of Range Ambiguous Targets



of this behavior are shown in Figures 9.12 and 9.13 for two second time around targets of Run 1 from Tape 12248. The dotted points represent flagged second time around centroids. The 0 represents unflagged data of only a single CPI width. The + represents the range corrected data where the actual range scale to the right applies.

Figure 9.14 is a photograph of second time around flagged centroids (red) from scan 585 to scan 645 and corresponds to the target of Figure 9.12 which is at a bearing 180°. The corresponding data for the target of Figure 9.13 is shown in Figure 9.15. Note the pairing in range where the low prf centroids appear at the shorter range and the high prf centroids at the longer range where the separation is 13.54 nmi.

9.4 MTD Anomalous Detections

Introduction

Anomalous detections were noted on MTD data tape 12448 of August 6, 1975 with the following characteristics:

1. Primitive reports are obtained at multiples of 7 radar scans at multiple ranges separated by ~ 1.6 nmi at 176° and 270° clockwise bearing from north.

2. Most doppler filters are excited at the range, azimuth bins in question with fairly uniform normalized strengths at the output of the doppler filters. Normalized strengths are in the 20 to 30 range and thus, not particularly large in value. Usually 6, 7 or all 8 doppler filters are excited. A possible mechanism which can cause such responses is a repeater jammer which recirculates, phase modulates and retransmits the received pulses multiple times during a CPI at multiples of 7 antenna scans.

Discussion

Figure 9.16 is a PPI-like photograph of a time exposed portion of the primitive report data from scans 1130 to 1746 on MTD data tape 12248. The color code indicates the number of doppler filters which are excited in a range-azimuth bin. Visible on this photograph are the anomalous detections at a bearing of ~ 180° from North (at the top of the photo). (Data from the upper quadrants was not recorded on this tape at NAFEC and thus these regions are blank). Range rings are separated by 2 nmi. Note the anomalous detections in the window ac 11.125 nmi and similar detections at the same bearing at other ranges separated by ~ 1.6 nmi.

Figure 9.12 Second Time Around Target
Run 1 - Tape 12248

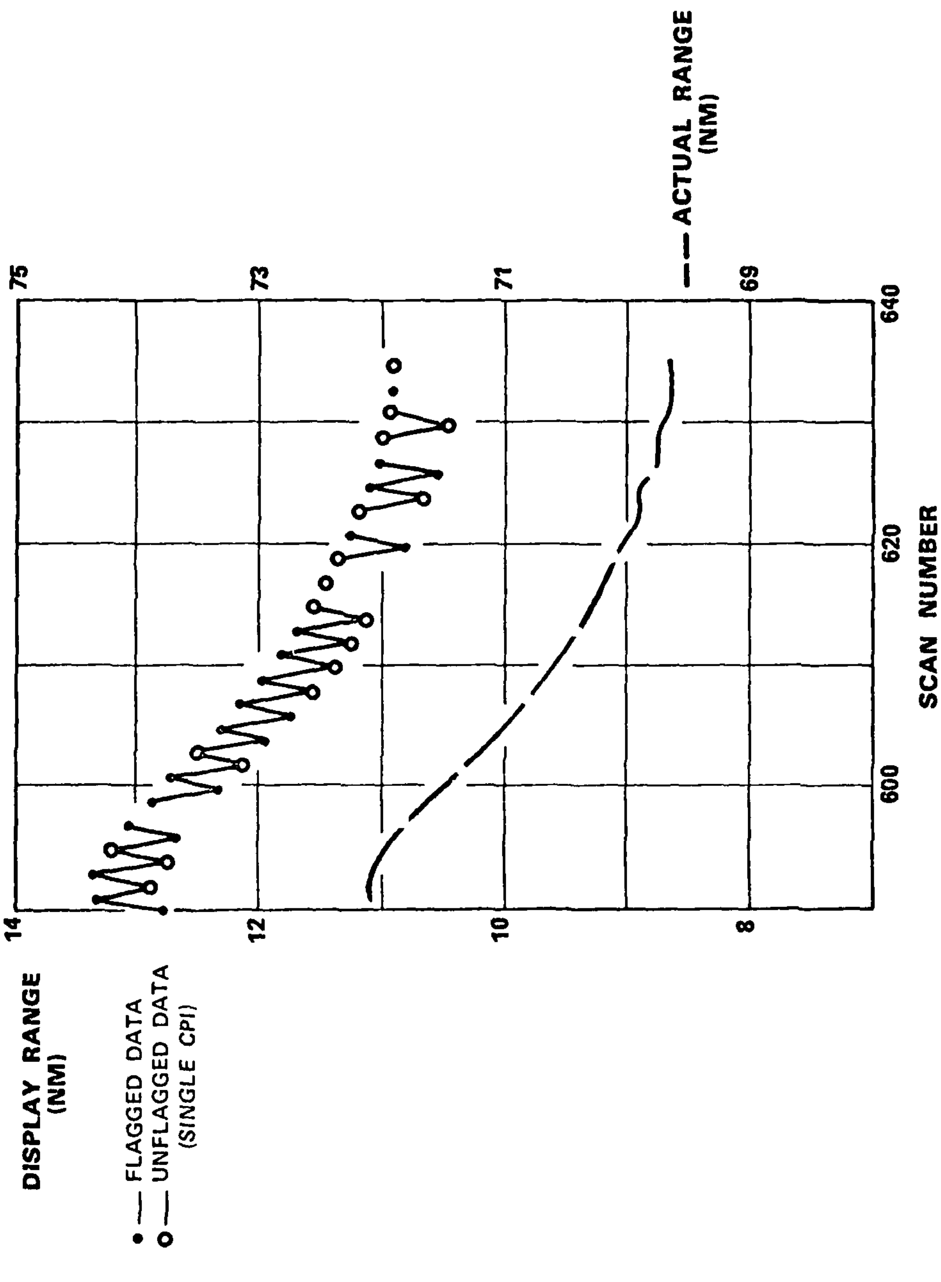
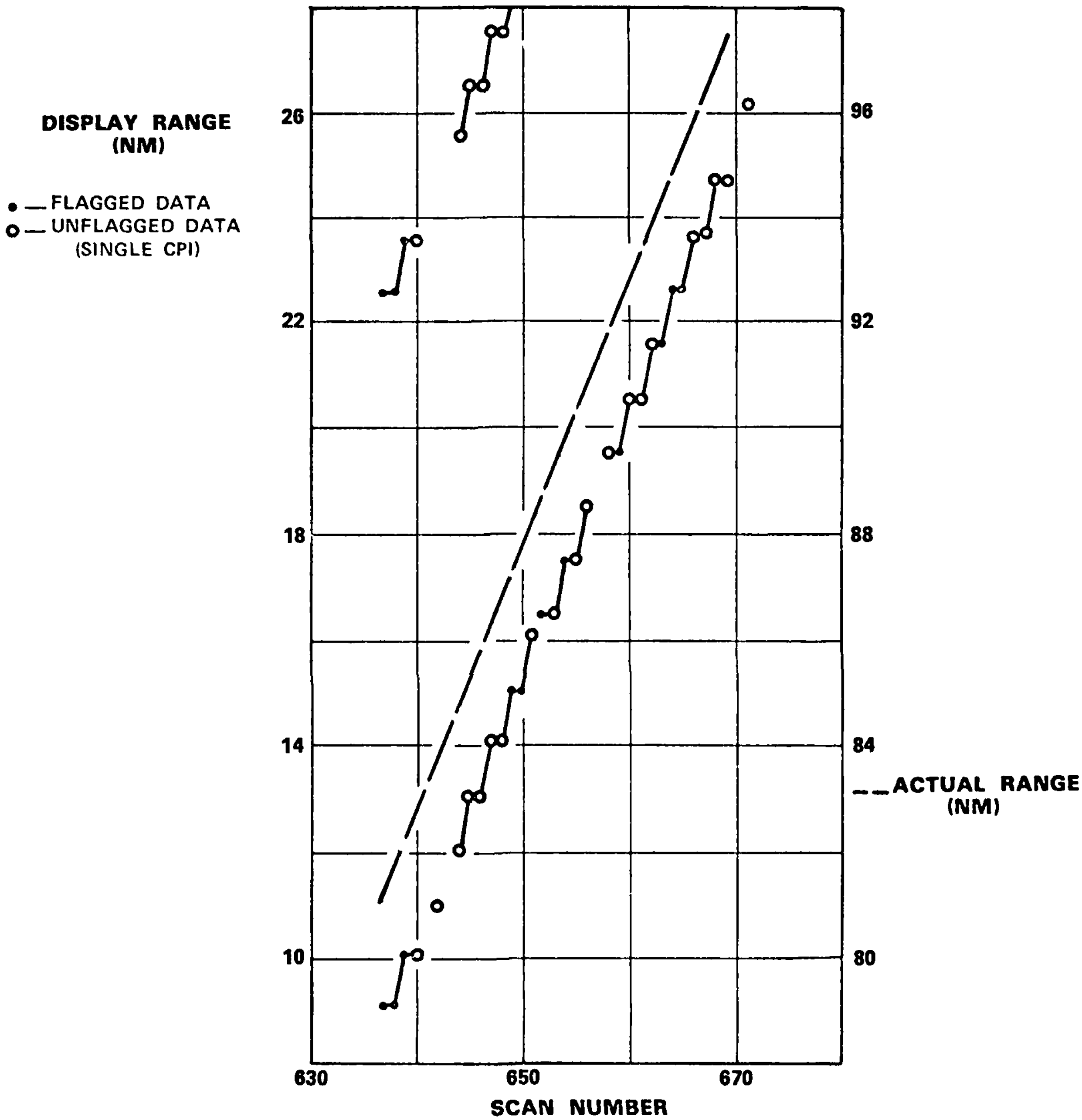


Figure 9.13. Second Time Around Target
Run 1 - Tape 12248



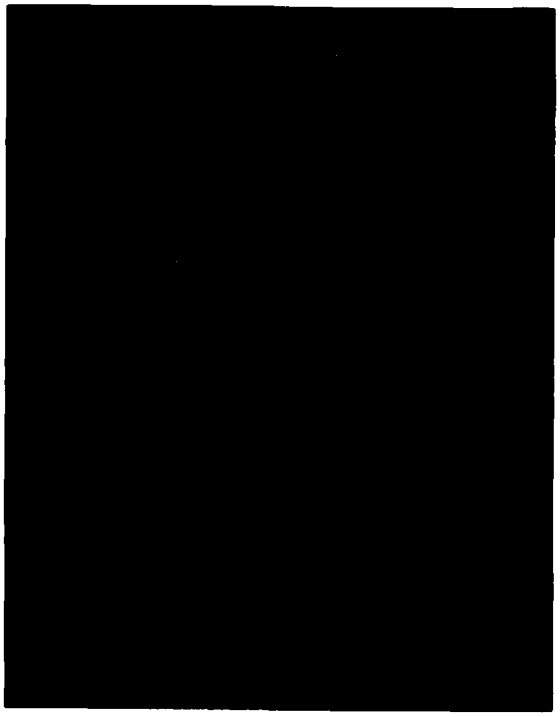


Figure 9.14 Second Time Around Target of Figure 9.12

Run #1
Tape #12248
Scan 585-645
Flag 10
10 Mi Range Rings

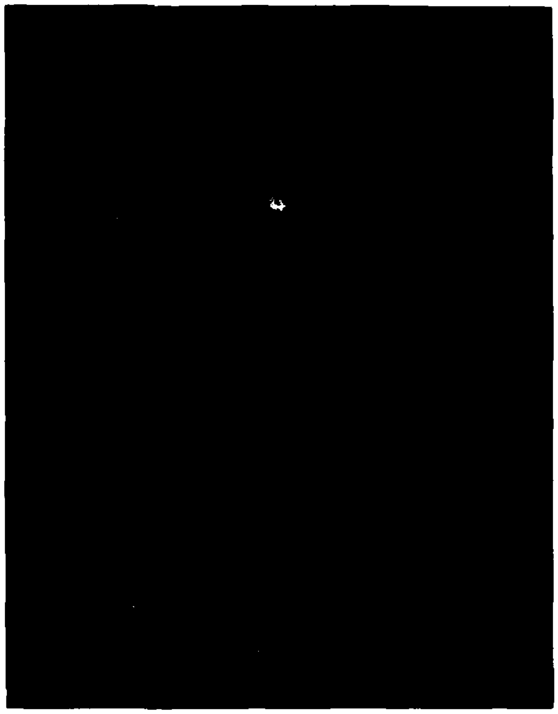


Figure 9.15 Second Time Around Target of Figure 9.13

Run #1
Tape #12248
Scan 630-670
Flag 10
10 Mi Range Rings

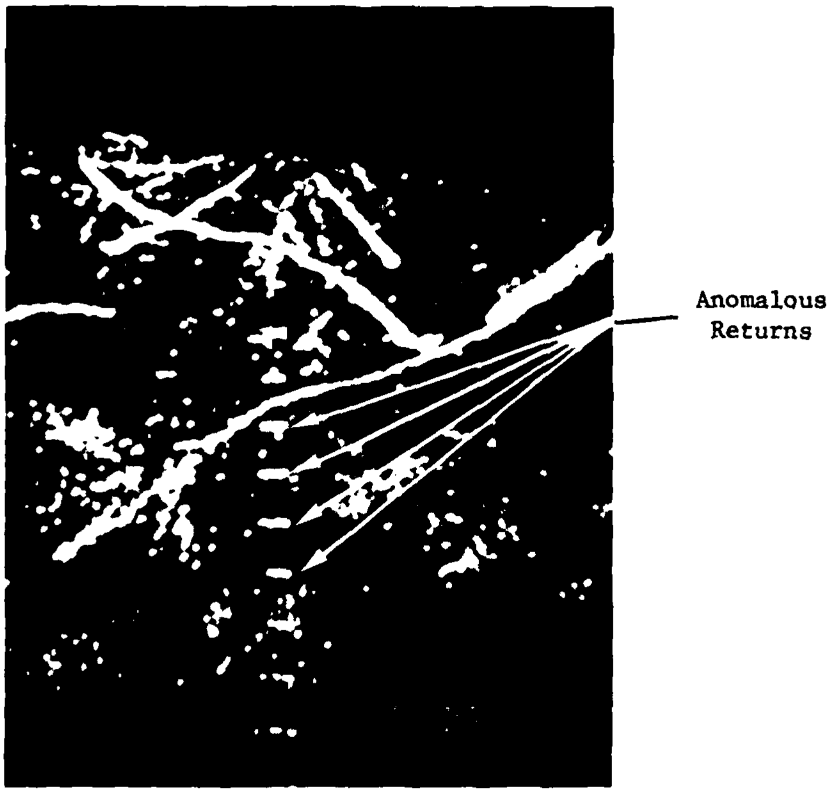


FIGURE 9.16

TIME EXPOSED MTD DATA

On earlier scans these anomalous detections are also present at 270° (see Figure 9.4). Data from two typical detections were obtained at the earlier time (scans 576 to 639) via a data hook routine and the tabulated results are shown in Figure 9.15.

Figure 9.17 is a range, bearing plot of these detections where the base number is the scan number of the detection chosen such that Scan 576 corresponds to 1, Scan 583 corresponds to 8, etc. The exponent or superscript value indicates the prf number of the CPI (see lower right of Figure 9.17). The following observations can be made from the figure and the tabulated data:

1. Detections are present at both ranges (9.5 and 11.125 nmi) on the same scan in most cases.

2. Detections occur at multiples of 7 scans.

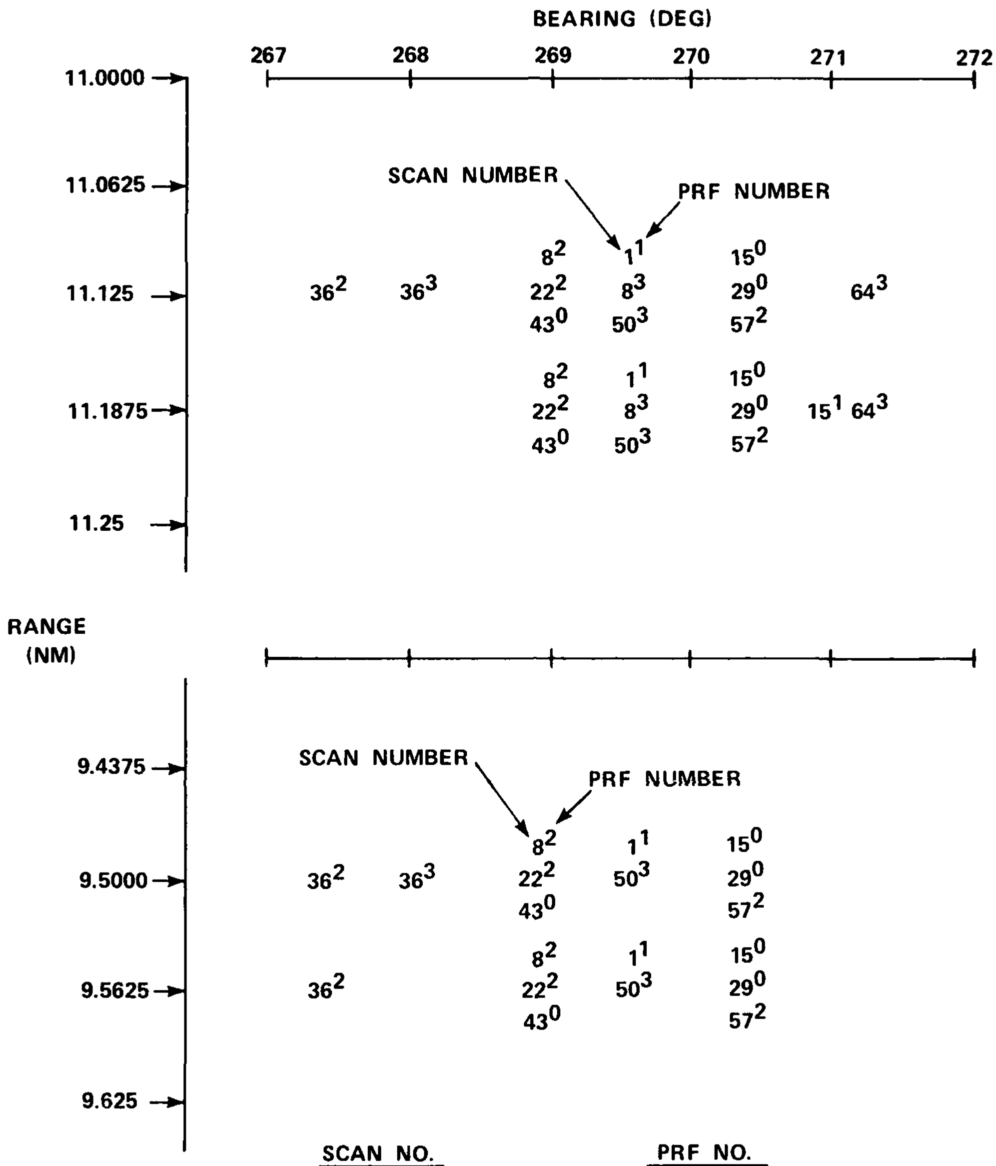
3. At most, 2 CPIs and 2 range gates are excited (range quantization is 0.0625 nmi).

4. The same range gates were excited (11.125 and 11.1875 nmi) for another hooked detection at 176.5° at a later time (scans 737 through 793. Not illustrated in Figure 9.17. See Figure 9.4).

5. Most doppler filters are excited at the range-azimuth bins in question with fairly uniform normalized strengths at the output of the doppler filters. This indicates a noise-like input signal synchronous with the radar transmissions which can yield similar amplitudes after the 8 point fft.

The only mechanism which can be conjured up at the present time to satisfy the observations is a repeater which recirculates, phase modulates and retransmits the received pulses multiple times during a CPI at multiples of 7 antenna scans.

FIGURE 9.17 ANOMALOUS MTD RESPONSES



SCAN NO.	
576 ↔	1
583	8
590	15
597	22
604	29
611	36
618	43
625	50
632	57
639	63

PRF NO.	
0 ↔	L
1	H
2	L+Δ
3	H+Δ

10.0 TRACKER DEVELOPMENT

Simple Tracker

To evaluate the usefulness of various parameters extracted during the centroiding process, it was necessary to compare the characteristics of these parameters for tracks and for clutter. Initially this was done manually to expedite the development of the centroiding algorithm and to allow detailed considerations of the impact of the selected procedures on the resultant centroids.

However, to assess statistically the nature of the parameters, it becomes necessary to have available a technique for automatically designating firm track centroids so that large numbers of samples can be observed. This was done by modifying an in-house off line range bearing α, β tracker optimized for an ASR to accept the new MTD centroids as input. In particular the ASR tracker was developed for the Miami Task IV effort (see Reference 7) and detailed description is given in Appendix B. The update logic for this ASR tracker is given in Figure 10-1 from which it can be seen that there are four basic track states; new tentative (NT), Tentative (TT), Firm (FT), and Fixed (Stationary - ST). Centroids are used to update Fixed tracks, Firm tracks, and Tentative tracks in that order. Unused centroids initiate New Tentative tracks. Only range and bearing is considered in developing these tracks, thus little modification was required.

Selective Simple Tracker

To assess the usefulness of various parameters in aiding the tracker, the simple tracker above was modified to incorporate a test on the centroids prior to initiating a new tentative track file (see Figure 10.2). Communications with the centroid files from the other track update logics was unaffected, commensurate with the conclusions of Section 9 that all centroids must be available to update already existing tracks. Various tests could be inserted in the test prior to new tentative track initiation to allow assessments of the associated parameter(s).

MTD Doppler Velocity Tracker

This would be a full scale MTD tracker design to make maximum use of the MTD data. The design calls for the centroid selection logic found most effective by the Selective Simple tracker above, plus a modification of α, β update logic to incorporate doppler velocity tracking. (One particular approach to this feature is studied theoretically for a maneuvering target in Section 12). The purpose here would be to evaluate the improvement in track quality achieved by including the doppler velocity measurement and thus verifying the need for a doppler velocity measurement. (As shown in Section 11, it would be necessary to select the centroids used in this process to avoid

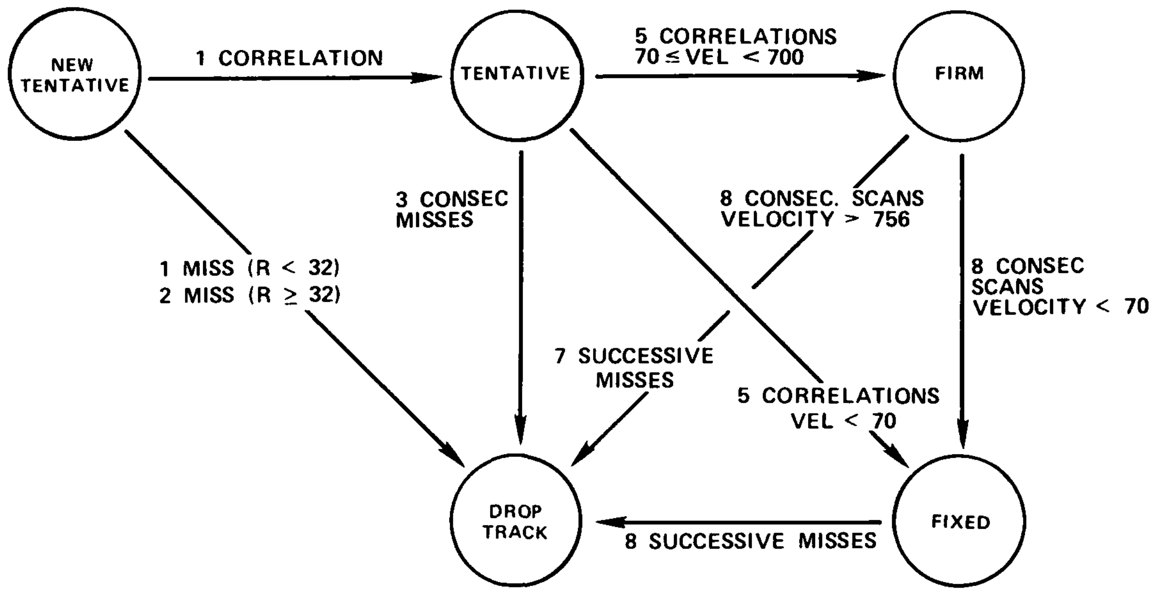


FIGURE 10.1 SIMPLE TRACKER UPDATE LOGIC

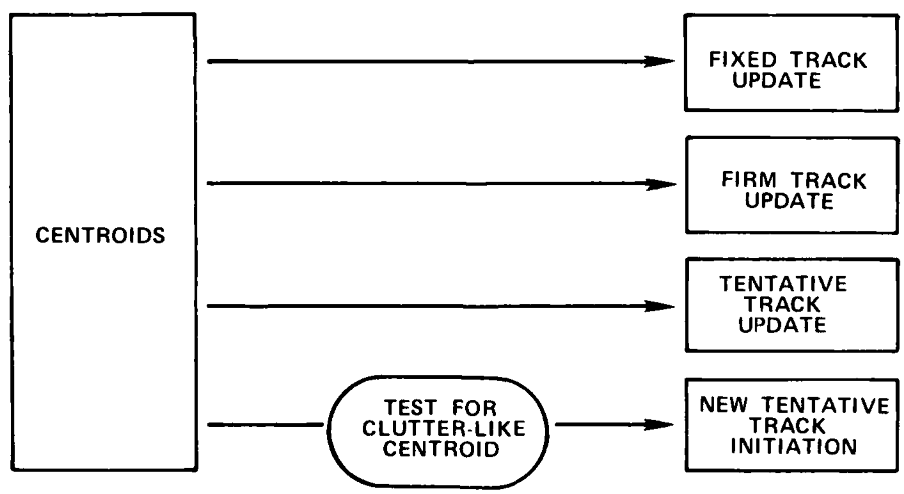


FIGURE 10.2 SELECTIVE SIMPLE TRACKER
CENTROID SELECTION SCHEME

the inclusion of spurious measurements resulting from JEM or propeller modulation. Several techniques are developed based on the parameters discussed in Section 8). In addition, due to the uniqueness of the measurement scheme (i.e., range, bearing, and sometimes doppler velocity) several potential update schemes would be evaluated.

Other features to be tested would be a hinting scheme where the doppler velocity measurement could be used for early turn detection and allow appropriate tracker compensation to follow the target. Also, the doppler measurement could be used to improve estimates for correlation gates of new tracks to improve the correlation probability for next scan centroids. In particular, for first scan new tracks, the doppler measurements could be used to offset the search window on the second scan to improve new track initiation probability (if this effect is significant, this search may be reduced, reducing the false track initiation probability, further lowering tracker loads and improving the overall quality of the output display).

Finally, the potential exists that the range rate measurement along with the tracker R DOT values could also be used to resolve centroids for proximate or crossing (but not overlapping) tracks.

This phase of the tracker development was not completed.

11.0 TRACKER RESULTS

Introduction

The statistical description of the firm track centroids generated by the simple tracker (see Section 10) has been discussed in Section 9 in the context of developing parameters of use in identifying centroid type as an aid to the tracker. The following two subsections discuss two such aids; the reduction of tracker loads by the inhibiting of new track generation for clutter-like centroids, and the selection of valid doppler velocity measurement data. In addition, the second study gives a qualitative assessment of a simple table look-up scheme developed in Section 12 for computing doppler velocity from the centroid doppler bin data.

11.1 Tracker Load Reduction Scheme

During the initial experiments at NAFEC with the MTD prototype, it was found that tracker loads in clutter could be significantly reduced by the suppression of single CPI centroids within the first 10 to 20 miles (a selectable cutoff range). These results were the first indication of the potential usefulness of the additional MTD parameters. However, as indicated in Section 9, it is not desirable to completely suppress single CPI returns as valid targets occasionally obtain configurations which can result in such returns. In addition, Section 9 demonstrated several parameters besides number of CPIs which may be of use in selecting centroids.

One philosophy consistent with the constraint of Section 9 is not to allow new tracks to be generated using clutter-like centroids, but otherwise process all centroids as before, ignoring this additional information (see selective simple tracker, Section 10). This procedure as is shown significantly reduces the number of track files (and hence tracker loads) required while retaining virtually the same moving track structure.

The tests consisted of a series of runs with identically the same input centroid data (Run 1) but with different new track initiation logics, depending on the parameter (or parameters) to be tested. To identify these parameters being tested, the following labeling scheme was used:

A. $CPI_{min} = 2$	At least 2 CPIs (Azimuths) are required of centroid to generate NT track
B. $MFC_{min} = 2$	At least a Maximum Filter Count of 2 is required of centroid to generate NT track
C. $TFR_{min} = 2$	At least 2 filters excited (2 VRS words) for centroid to generate NT track

D. $NBR_{min} = 2$	At least 2 range-azimuth cells required of centroid
E. $MRE_{min} = 2$	At least 2 range cells in depth required of centroid
F. FLAG 3 SET	Do not initiate NT track if Flag 3 is set (Inconsistent Alternate Filter No. - low prf)
G. FLAG 4 SET	Do not initiate NT track if Flag 4 is set (Inconsistent Alternate Filter No. - high prf)
H. FLAG 5 SET	Do not initiate NT track if Flag 5 is set (Inconsistent Amplitude Ratio)
I. FLAG 8 SET	Do not initiate NT track if Flag 8 is set (Inconsistent intra-CPI filter number)
J. FLAG 10 SET	Do not initiate NT track if Flag 10 is set (Possible second time around target)
K. $CPI_{min} = 2$ and $MFC_{min} = 2$	Constraints A and C "anded" together

Note that condition K requires two parameters, number of CPIs and maximum filter count, to exceed certain minimums before a new track was initiated by the test centroid. These labels are combined with the run numbers (1-7) to identify each of the test results (i.e., 1A, 2B, etc.) some samples of which are given in Table 11.1. Of particular interest in this table is a comparison of the various conditions (A $\rightarrow$ K) for Run 1. The first line gives the total numberof new tentative (NT), tentative (TT), firm (FT), etc track files (i.e., not updates, just file initiations) generated by the tracker for the run when no constraints were applied to the new track initiation logic. Subsequent lines give the same quantities for the various constraints. (Note, columns denoted TT $\rightarrow$ ST, FT $\rightarrow$ ST, indicate the number of stationary tracks which were generated from tentative tracks and firm tracks respectively. The number of stationary tracks resulting from firm track files has been subtracted from the FT column and labeled Firm Air Tracks, as this number is representative of firm tracks with a velocity greater than 70 knots).

Of particular importance is the sizeable reduction in the number of tentative and new tentative tracks while the Firm Air Track count is little changed. In fact as shown below, no moving air tracks of any sizeable length were lost by any of the constraints, including condition K which shows the largest reduction in tracker stores.(approximately 20 to 1).

TABLE 11.1 TRACKER LOAD STATISTICS

Run	Run/Condition	NT	TT	FT	TT→ST	FT→ST	Firm Air Tracks	Firm Track Centroids	Mean Firm Track Life (Scans)/Mean Blip Scan
1 (weather)	1- No Constraints	11473	2627	64	100	10	54	1938	39.1/0.63
	1A-CPI_{min}=2	1324	677	56	72	7	49	1876	42.47/0.67
	1B-MFC_{min}=2	1834	749	49	60	3	46	1828	47.15/0.69
	1C-TFR_{min}=2	3079	1220	55	84	4	51	1869	
	1D-NBR_{min}=2	2288	991	58	83	6	52	1883	
	1E-MRE_{min}=2	1588	714	49	66	3	46	1904	
	1F-FLAG 3 set	11473	2627	64	100	10	54	1938	
	1G-FLAG 4 set	11473	2627	64	100	10	54	1938	
	1H-FLAG 5 set	11473	2627	64	100	10	54	1938	
	1I-FLAG 8 set	11464	2631	64	99	10	54	1934	
	1J-FLAG 10 set	11432	2604	62	102	8	54	1909	
	1K-1A + 1B	503	300	48	47	4	44	1815	47.62/0.71
Others 2-6 (weather)	2-No Constraints	3554	857	32	26	1	31	757	
	3 "	5004	1172	29	26	1	28	790	
	4 "	8269	1493	77	28	3	74	2049	
	5 "	1649	256	25	3	0	25	450	
	6 "	9173	2794	92	105	6	86	1645	
7 (angels)	7-No Constraints	3880	1093	17	142	8	9	121	13.82/0.48
	7K-Conditions A + B	656	337	14	93			91	11.79/0.57

NT = New Tentative
TT = Tentative
FT = Firm Track
ST = Stationary (< 70 knots)

Thresholding the number of CPIs parameter in centroids prior to track initiation (condition A) appears to be the most effective single parameter algorithm for reducing tentative track loads, with Maximum Range Extent (condition E) and Maximum Filter Count (condition B) the only others of note. Interestingly, the last two parameters produce a slightly lower number of firm tracks, although presumably these are clutter tracks which are deleted as no moving tracks were noted as being lost (see below).

In Table 11.1, Runs 2 to 6 are included for comparison of the current processor load requirements to track these data. Run 7 is included in slightly more detail to indicate the impact of selected parameters on the reduction in tracker loads for angels (here the reduction is about 6 to 1 for condition K).

To verify the effectiveness of this approach, photographs were made of a PPI display of the resulting firm track centroids for each of the cases. Figure 11.1 shows four of these photographs, the no constraint condition, and constraints A, B, and K (= A + B). As can be easily verified from these photographs, not a single track has been lost by the inclusion of the constraints. The only differences in the photos is the disappearance of a few short clutter tracks.

To further verify the effect of these constraints, the firm track blip scan and track life distributions were computed for each of the runs illustrated in Figure 11.1 (and Run 7), the average values of which are included in Table 11.1 in the right hand column. Interestingly, in every case these qualities of the tracks are improved over that of the no constraint case. Detail consideration of the distributions themselves (see Figures 11.2) indicate that the effect here is almost entirely due to the removal of short tracks (20 scans or less), with the characteristics of the longer tracks remaining virtually identical.

In conclusion, it therefore appears that these constraints can be used within the track initiation logic to considerably reduce the track loads induced by clutter returns with virtually no effect on the resultant firm air track picture.

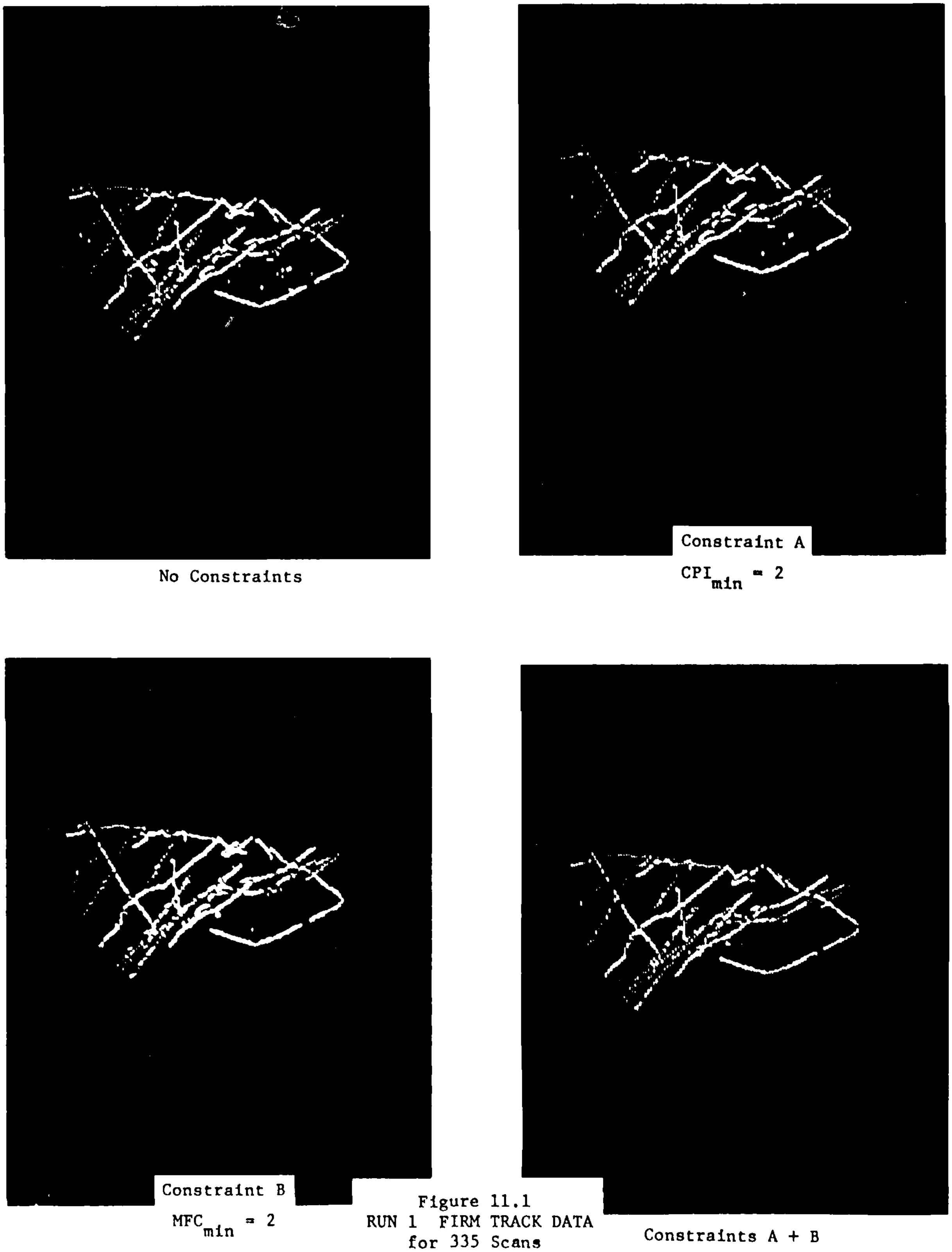
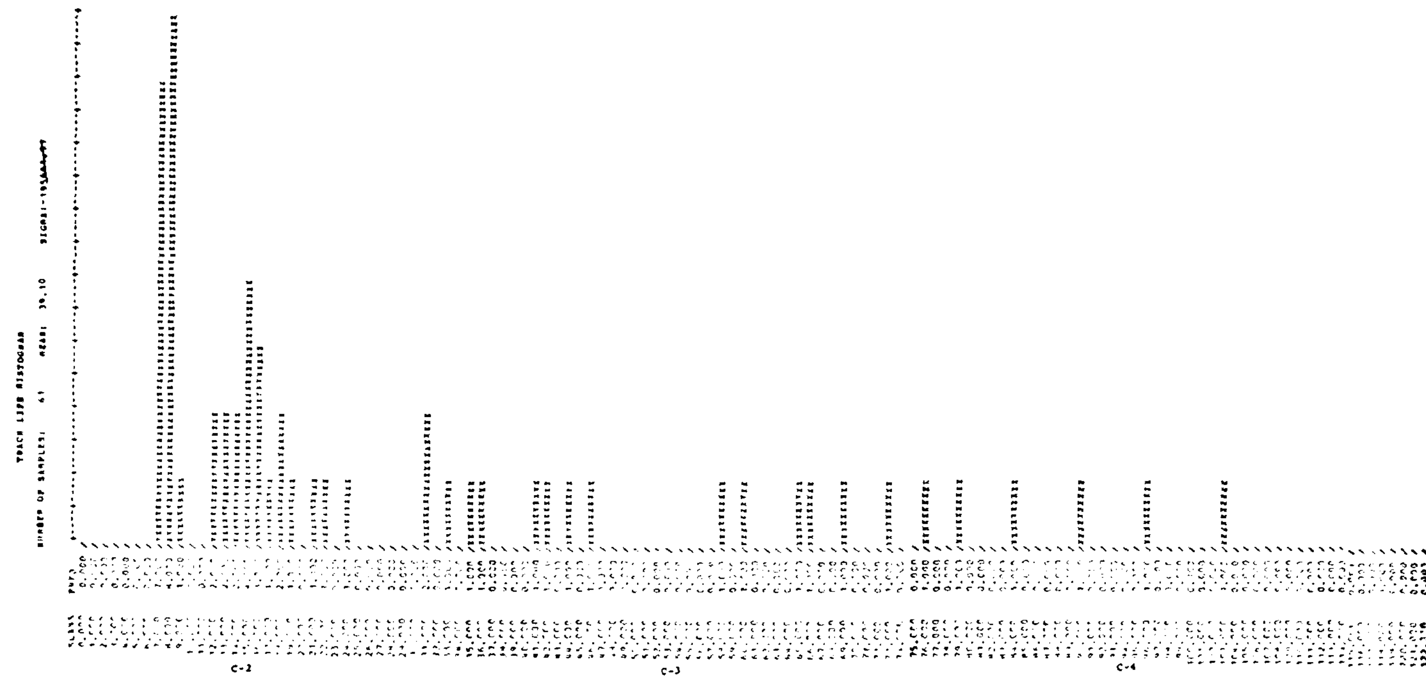


Figure 11.1
RUN 1 FIRM TRACK DATA
for 335 Scans
(20 nmi range rings)



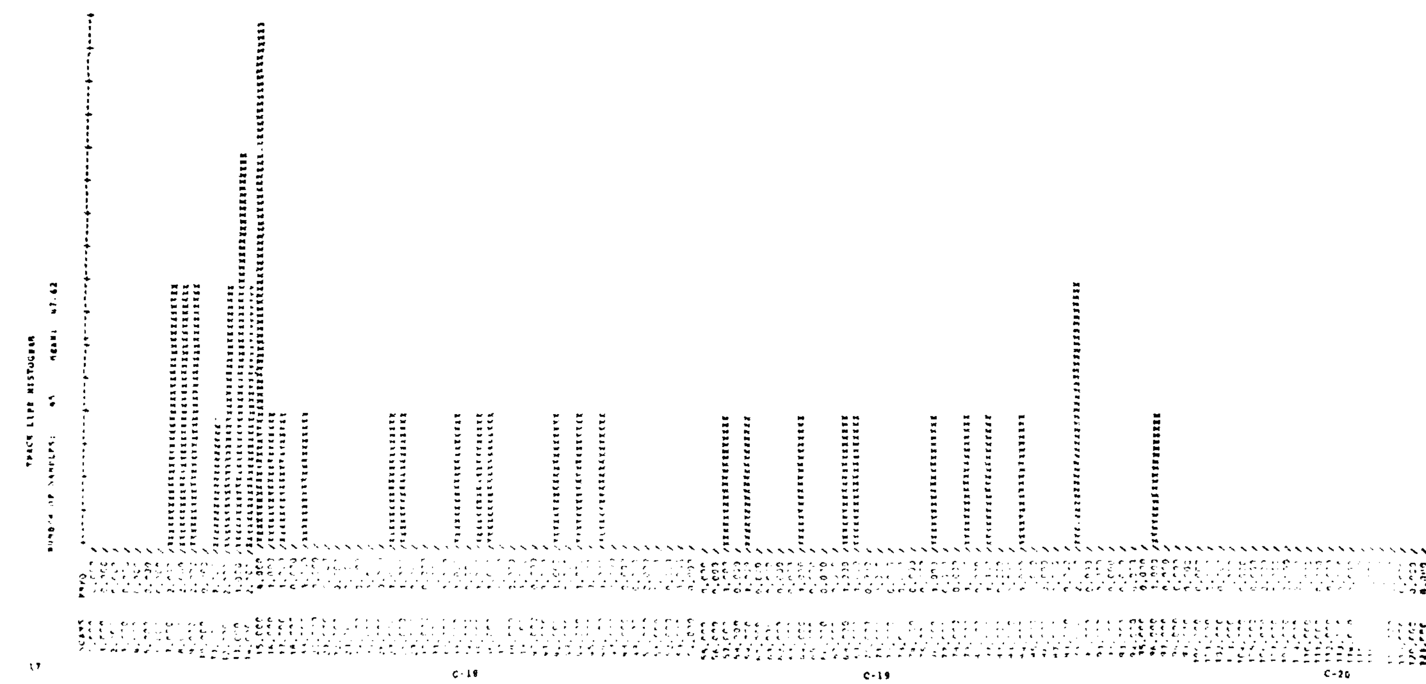
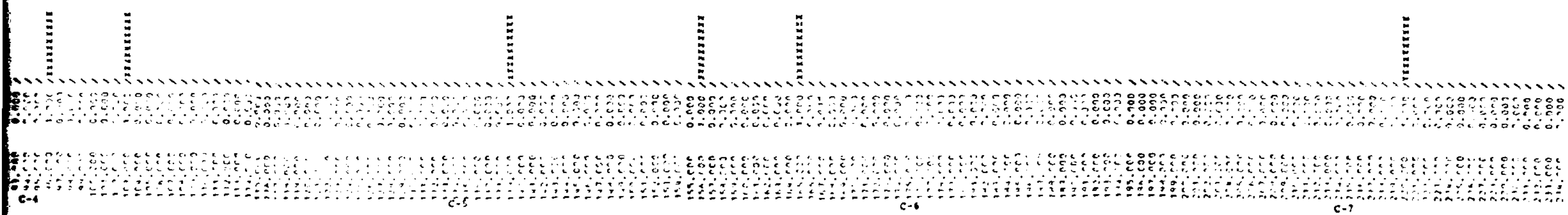


FIGURE 11.2 T

THIS [illegible] PRACTICABLE
[illegible]

Run 1 - No Constraints



Run 1 - Constraint K

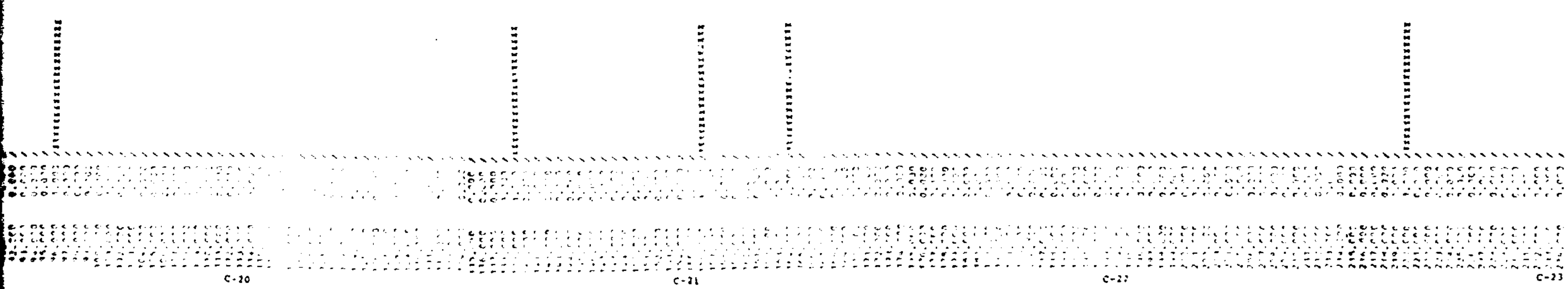


FIGURE 11.2 TRACK LIFE DISTRIBUTION

11.2 Doppler Velocity

Once a tracker has been developed to operate with MTD centroiding algorithm developed in Section 8, it becomes possible to assess the quality of doppler velocity measurements which can be extracted from the doppler bin data of the VRS words. The basic measurements are in terms of the doppler bin numbers and associated PRFs which resulted from threshold crossing during the MTD processing. These numbers must be converted to a doppler velocity measurement representative of the targets radial velocity. There are several schemes for accomplishing this conversion (see Reference 8 for example), although the technique used here is a simple table look-up procedure developed in Section 12.

Table 11.2 is an extraction of the full table developed in Section 12 and used in the following. One extracts a radial velocity estimate using the high PRF doppler number and low PRF doppler number to address elements in this table. Unfortunately, as with all the schemes, there is an ambiguity in this estimate, an ambiguity which must be resolved using the tracker radial velocity estimate derived from positional data.

In addition, the presence of JEM, clutter, etc. can cause the centroiding algorithm to choose the wrong doppler bin numbers and spurious doppler velocities may result. Also, targets may only excite doppler bins on one PRF, yielding only one doppler bin number, hence no doppler velocity may be estimated.

Doppler Validity Assessments

Two constraints were considered for the doppler data prior to declaring the doppler data valid. The first was that the centroid for which the doppler velocity estimate was computed does not have any amplitude or doppler inconsistency flags (3, 4, 5 and 8) set nor the second time around flag (flag 10) set. The second constraint was that the tracker radial velocity estimate (R DOT) be within ±50 knots of the measured doppler velocity estimate (new R DOT). This second test is a result of the theoretical study developed in Section 12.2 for a maneuvering target. The value, fifty knots, is an estimate which is dependent both on the target model assumed as well as the tracker gains and thus represents a first estimate for the allowable velocity difference.

Based on these constraints, Table 11.3 lists the number of firm track centroids in each of the first six runs which had potential doppler velocity data and of those, which had valid doppler data (i.e., fit the constraints). As can be seen, overall, doppler data was available 83% of the time, although valid data by these criteria only 70% of the time (i.e., 84% of the firm track centroids with doppler data were valid).

HI PRF

LOW PRF	1	2	3	4	5	6	7	8
1	22.05	-99.75	485.85 -93.40	364.70 -212.45	371.05 -206.10 -333.50	250.05 -327.00	256.40 -449.00	15.70 136.75 -443.00
2	+29.85 -549.50	35.15	492.35 -84.80	497.65 -79.50	379.6 -200.6	384.90 -320.50	264.2 -315.5	148.45 269.50 -433.50
3	164.05 -542.00	41.65 -535.00	48.65	506.10 -72.00	513.10 -192.15	391.40 -185.20	398.40 -308.00	157.10 277.10 -300.85 -421.00
4	171.85 -406.00	178.70 -528.50	57.25 -522.00	64.05 -64.05	521.70 -57.25	528.50 -178.70	406.2 -171.85	290.90 413.00 -290.85 -413.00
5	307.60 -398.00	185.25 -391.00	192.20 -513.00	72.0 -506.0	-48.65	535.00 -41.85	542.00 -164.05	300.60 421.00 -157.10 -277.05
6	315.45 -264.20	320.75 -384.50	200.60 -379.50	79.50 -497.75	84.8 -492.25	-35.15	549.75 -29.85	433.35 433.35 -148.45 -269.50
7	449.0 -256.40	327.25 -250.05	206.10 333.60 -371.00	212.45 -364.50	93.40 -485.50	99.75	-22.05	442.70 -15.70 -136.75
0, 8	456.80 -117.95	468.80 -106.26 -243.55	342.20 477.40 -231.70	220.85 356.25 -220.85 -356.00	231.70 -342.00 -477.00	106.25 243.55 -468.50	117.95 -456.50	128.05 7.05 -7.05 -128.05

\+ – INBOUND
\- – OUTBOUND

TABLE 11.2 DOPPLER RANGE RATE TABLE

TABLE 11.3

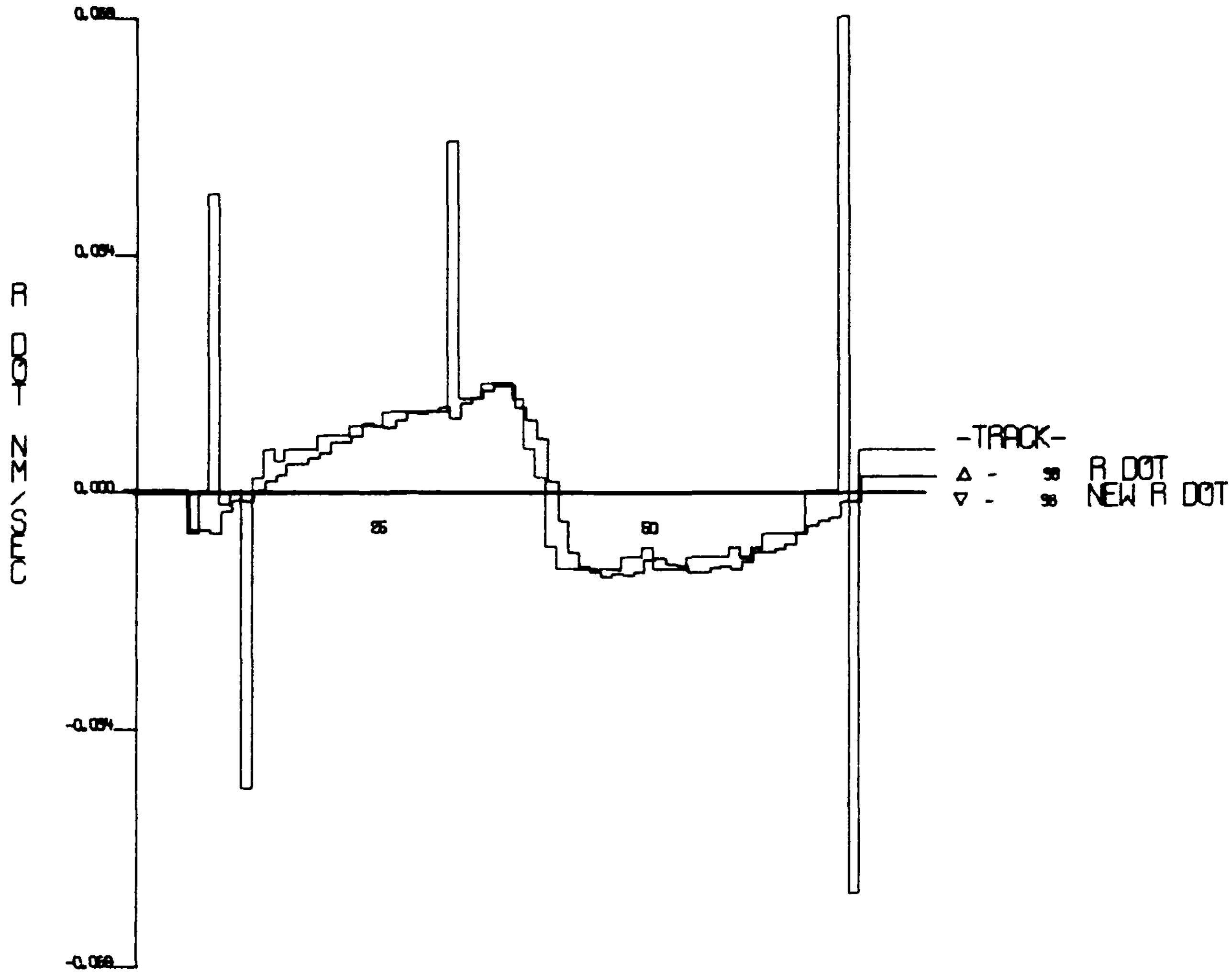
Run No.	No. of Firm Track Centroids	No. of times doppler $\dot{R}$ can be decoded	No. of times doppler $\dot{R}$ fits constraints
1	1938	1613	1385
2	757	608	525
3	790	638	521
4	2049	1762	1483
5	450	394	349
6	1645	1324	1063
Totals	7629 (100%)	6339 (83%)	5326 (70%)

Comparison of R DOT to New R DOT

To illustrate the relationship between the tracker radial velocity estimate (R DOT) and the MTD doppler velocity estimate (new R DOT), computer plots of these parameters were generated for several tracks. (See Figures 11.3 and 11.4 for examples). Plots were made with each track for unconstrained doppler estimates and for each of the constraints. In these plots R DOT is plotted in one color (blue) while new R DOT is plotted in another (red) for each scan of the track. Thus direct comparisons are possible between the two radial velocity estimates on a scan-by-scan basis for each track.

Figures 11.3 and 11.4 are two such plots for maneuvering targets. As can be seen, several invalid doppler velocity measurements have occurred with the target in Figure 11.3A while in 11.4A only one invalid point (about scan 130) is visible. Figure 11.3B, and 11.4B represent the same tracks, except now those centroids for which the amplitude and doppler inconsistency flags were set caused a zero doppler velocity estimate (new R DOT) to be forced. In Figure 11.3B for example, several of the obviously incorrect doppler estimates in Figure 11.3A have been removed (forced to zero) although several still remain. Also, it appears that a few valid points have also been removed. Similarly for Figure 11.4B the invalid doppler estimate has been removed by the flag constraint, but so have a few valid measurements.

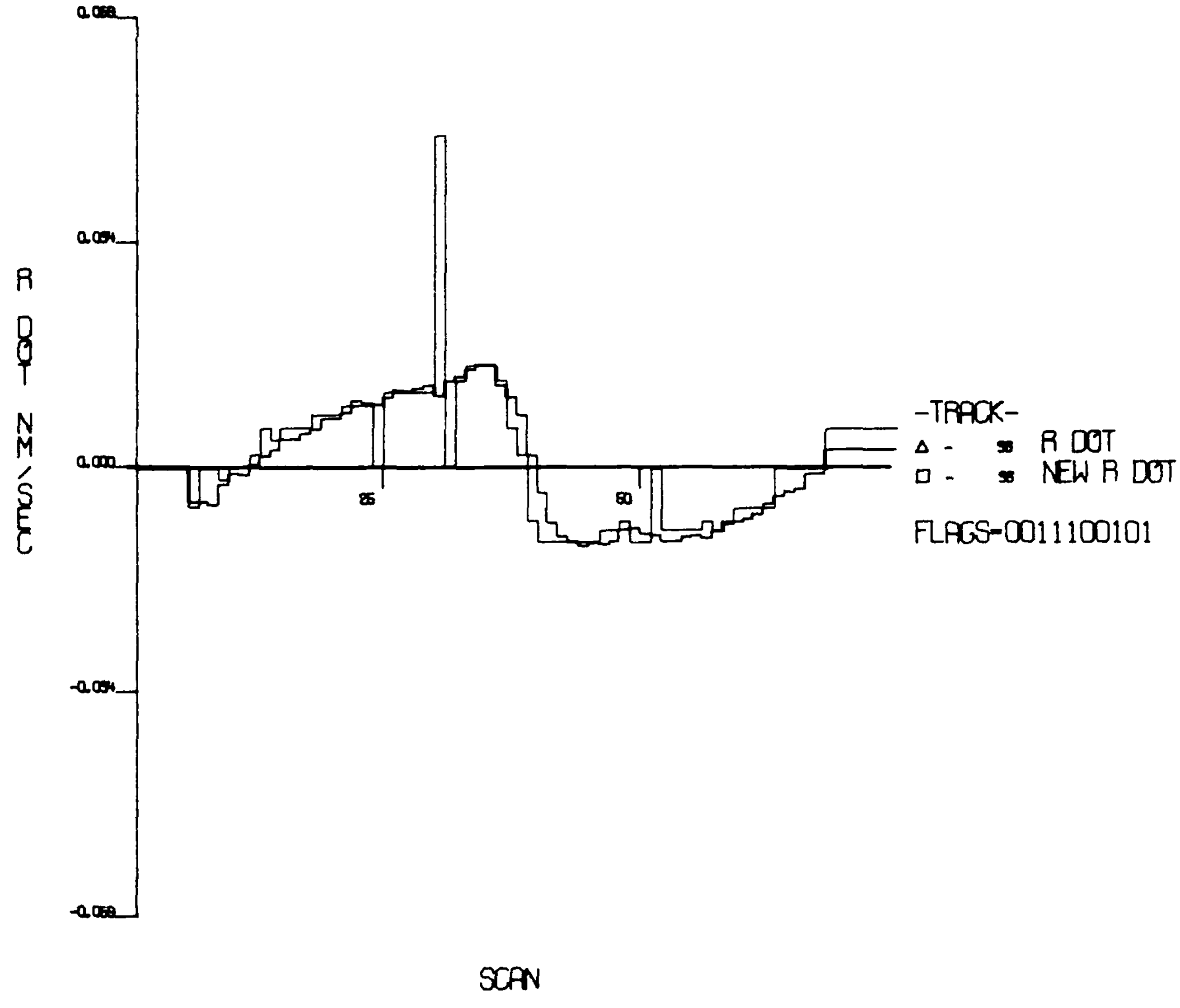
Figures 11.3C and 11.4C show similar plots for the flag constraints amended to include the 50 knot comparison with the tracker radial velocity R DOT. Here all erroneous data has been deleted, as has considerable valid data, indicating these constraints are probably too strong. Further, it can be seen that where the track was rapidly accelerating in Figure 11.4C, the tracker was not following the doppler estimate within 50 knots, causing the doppler velocity to be dropped, an undesirable result. Undoubtedly a larger window size for the R DOT-new R DOT comparison will modify these results.



SCAN

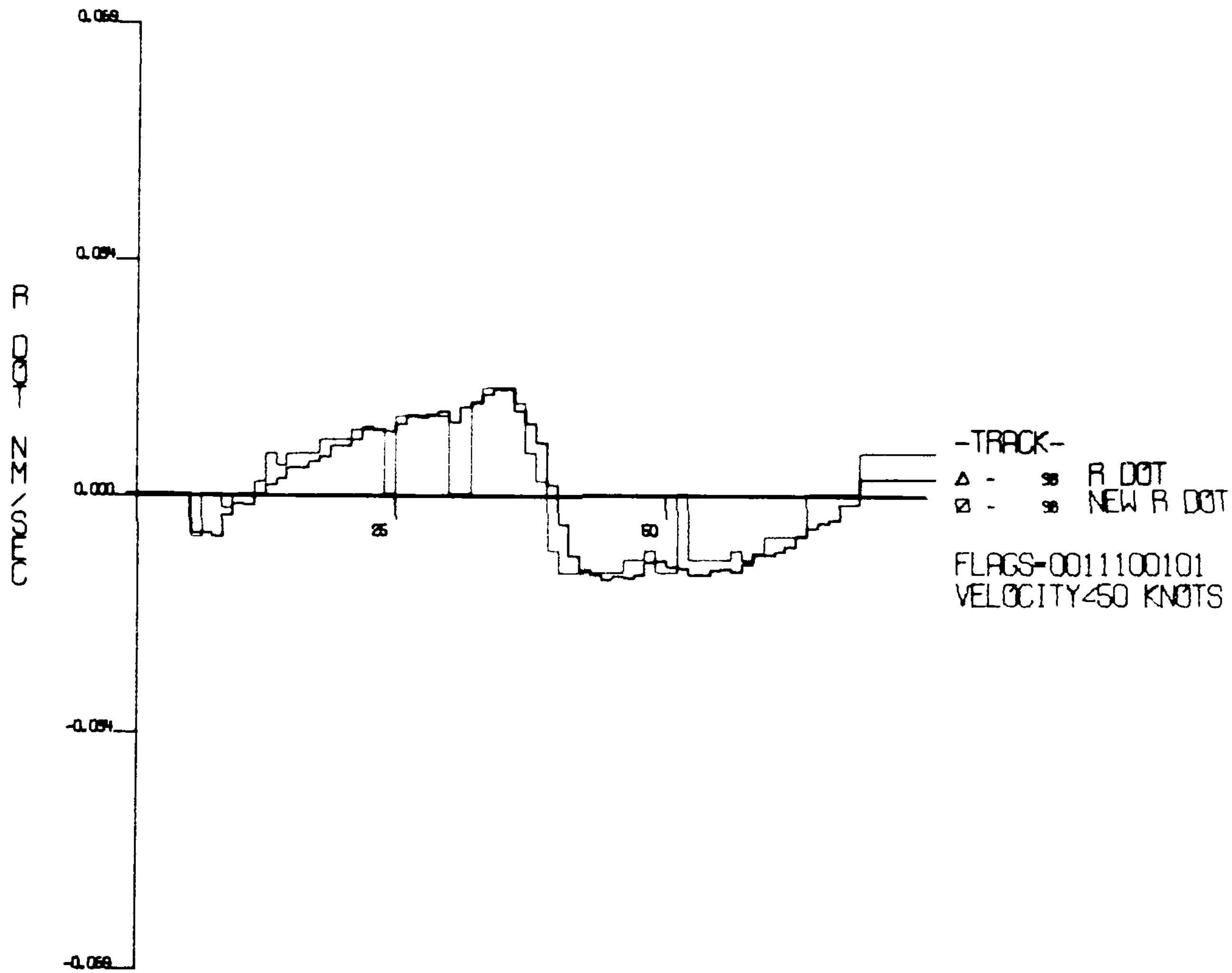
R DOT VS NEW R DOT

FIGURE 11.3A



R DOT VS NEW R DOT

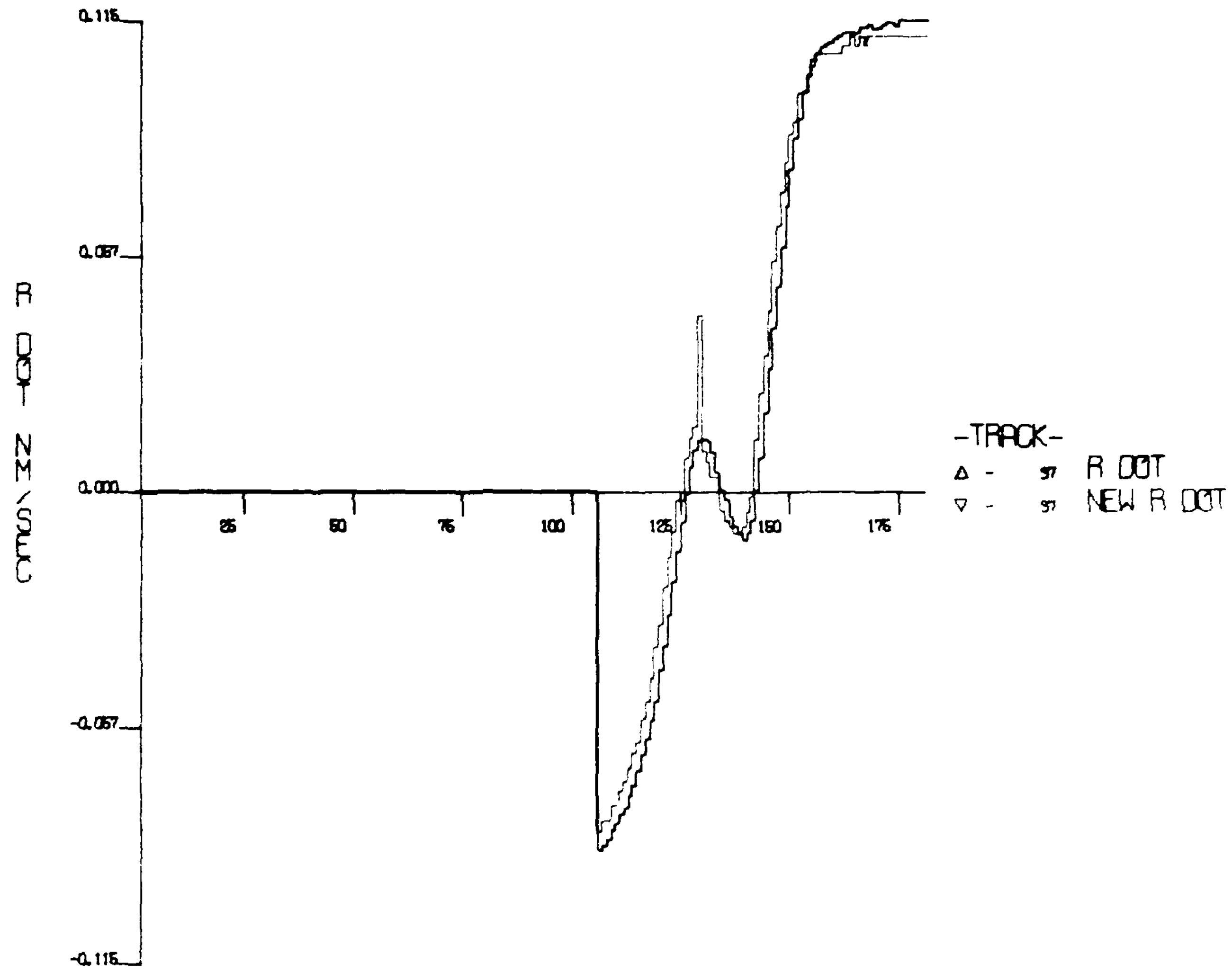
FIGURE 11.3B



SCAN

R DOT VS NEW R DOT

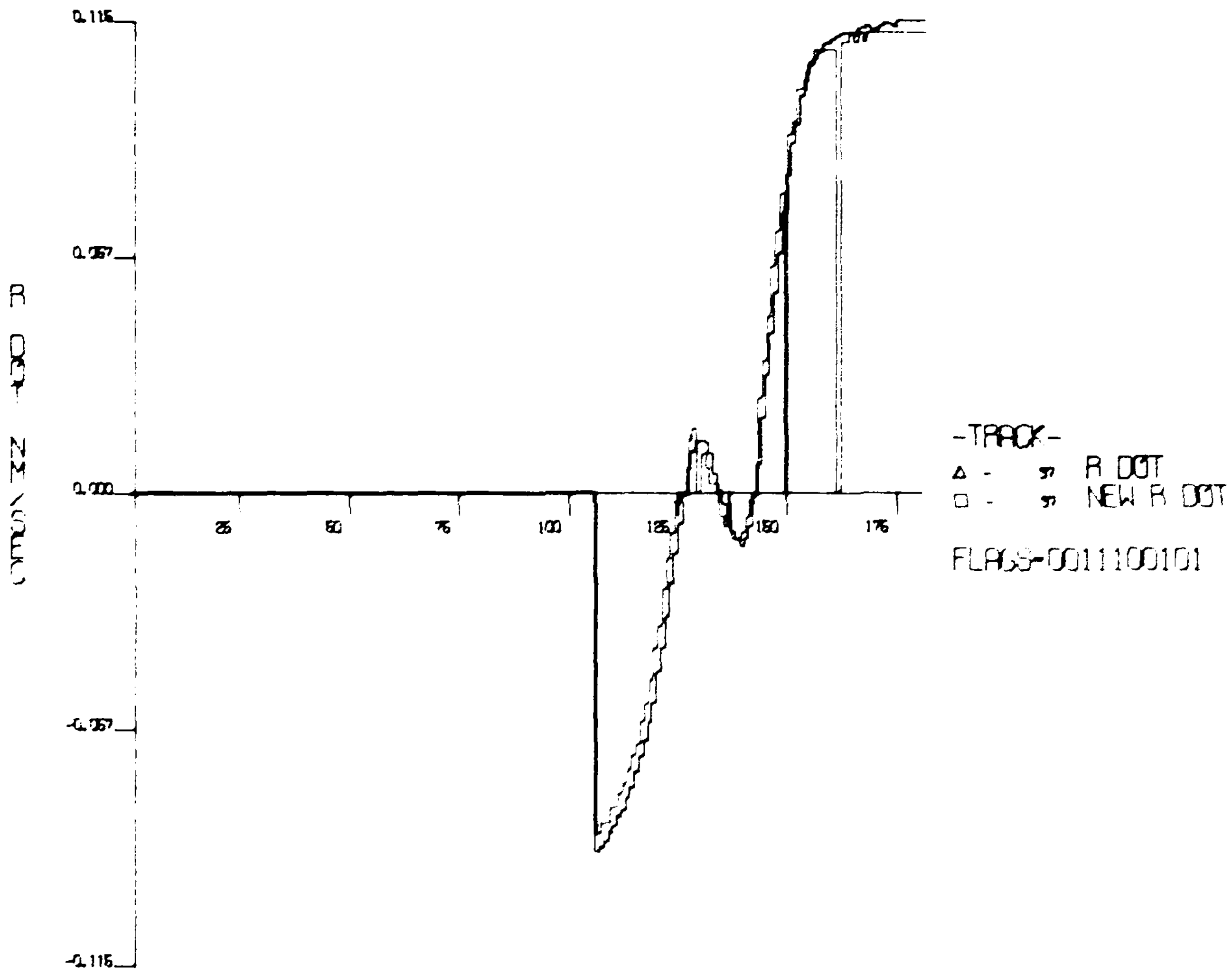
FIGURE 11.3C



SCAN

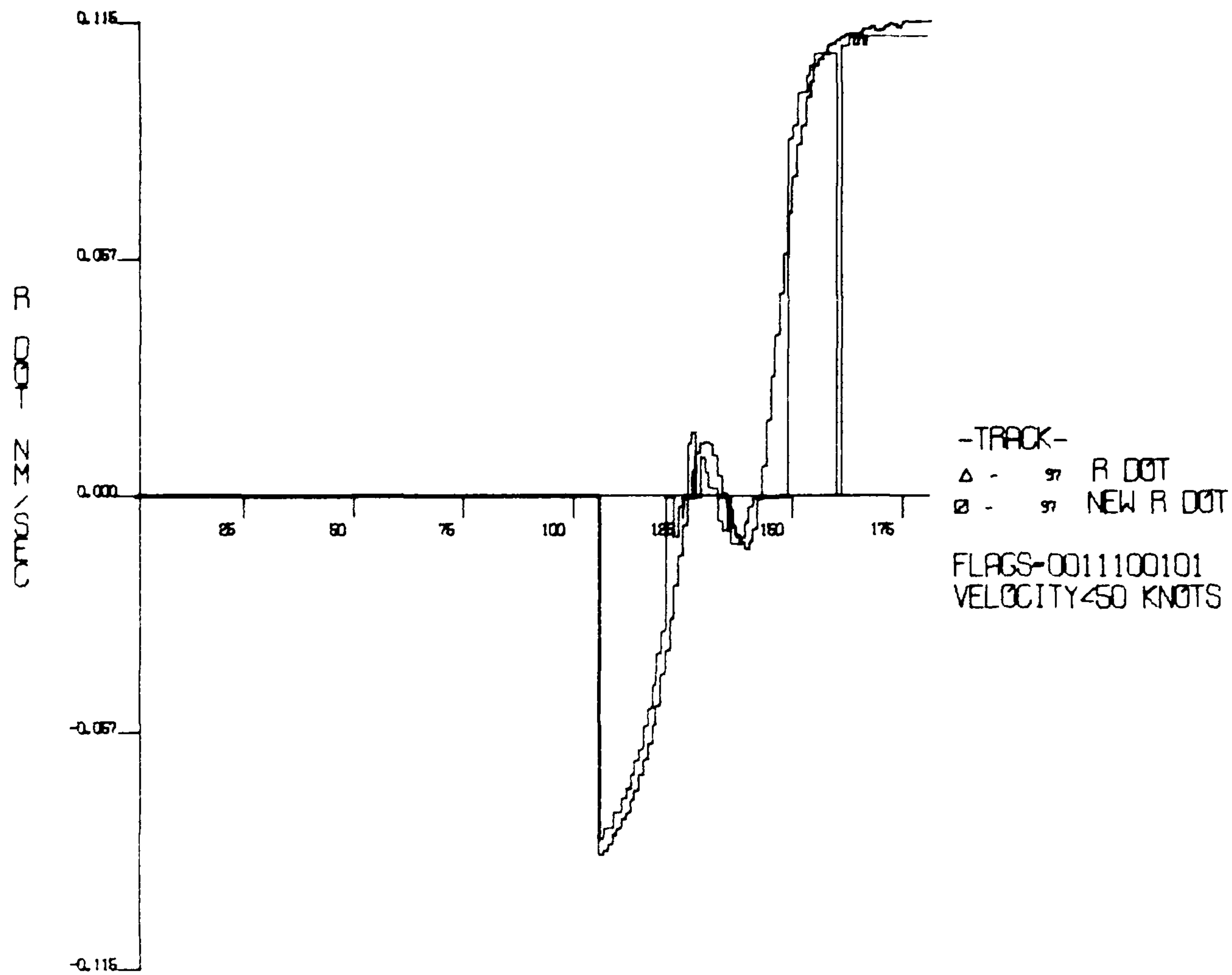
R DOT VS NEW R DOT

FIGURE 11.4, A



SCAN
R DOT VS NEW R DOT

FIGURE 11.4, B



SCAN
R DOT VS NEW R DOT

FIGURE 11.4, C

Interestingly, it can be observed on both plots, and in fact in all the plots generated, that the valid doppler velocity estimates (new R DOT) always precedes the tracker estimates (R DOT) to the new values when the track is accelerating. This is a direct consequence of the tracker lag inherent in the design of all α, β trackers (in fact in all Kalman filters) which try to fit the data with a straight line non accelerating model. As a consequence of this lag short term predictions are offset so that search gates are incorrectly positioned and the potential for dropping a track in the maneuver is increased. In fact, if the acceleration is great enough, track drop is assured.

Further long term predictions are severely affected by not only the acceleration, but the fact that the lagging velocity is used in making estimates. Thus it would appear desirable, particularly when the track is accelerating, to use the valid doppler estimates to improve the radial velocity estimates to enhance the track following capabilities of the tracker and the long term prediction potential. Also, discrepancies between the doppler measured velocity and the tracker value can be used to detect acceleration conditions early on to allow implementation of turn oriented logic.

Finally, it should be noted that the procedure using Table 11.2 has resulted in the generation of doppler velocities in close agreement with the tracker estimate values for the majority of the data points, implying the technique is viable.

AD-A086 962 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/9
MOVING TARGET DETECTOR DATA UTILIZATION INVESTIGATION.(U)
MAR 80 F R CASTELLA, M J FEIL, J T MILLER DOT-FA74WA-3423
UNCLASSIFIED JHU/APL/FP8-T-041 FAA-RD-80-29 NL

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12.0 ANALYTICAL STUDIES

This section consists of a compendium of theoretical studies developed in support of the analyses given in the previous sections. Two principal efforts are presented; development of a simple table look-up scheme for generating doppler velocity estimates from centroid doppler bin data, and a first attempt at designing a tracker which would utilize these estimates.

12.1 Doppler Table Development

In order to implement Table 11.2 by which target range rate can be determined from the doppler data, it is necessary to examine in detail the transfer characteristics of the MTD doppler filters.

The power transfer functions for the 8 MTD doppler filters are given by the following expressions (based on the references and private communications with Lincoln Laboratory):

$$|H_j(f_d)|^2 = \left|\sum_{k=0}^{7}\left[1 - \frac{1}{2}\cos\left(\frac{\pi k}{4}\right)\right]\cdot \exp\left[i\ 2\pi k\left(z - \frac{j}{8}\right)\right]\right|^2 \cdot 16\sin^4(\pi z) \qquad j = 1 \to 7 \tag{12.1}$$

$$|H_o(f_d)|^2 = 4\sin^2(5\pi z)/\sin^2(\pi z) \text{ (zero doppler filter)} \tag{12.2}$$

where $z = f_d/\text{PRF}$ and

f_d = doppler frequency in hertz

PRF = radar pulse repetition frequency for the CPI of interest

Equation (12.1) applies to doppler filters 1 through 7 and (12.1) applies to the zero velocity filter. The latter is referred to as 0 in Table 11.2. Graphs in dB of (12.1) and (12.2) as a function of z are shown in Figure 12.1 for filters 0 through 4. Filters 5, 6 and 7 are mirror images of 3, 2 and 1, respectively, about the z = 0.5 line. Also shown along the abscissa are the doppler frequencies and range rates which apply to the low and high prfs. As can be seen from these plots the 3 dB widths of the doppler filters are in the range of 10 to 15 knots. The numbers assumed for the prfs in the analysis are

	1120.8 Hz	1379.4 Hz	Scans 1, 3, 5, ...
	1113.1	1367.7	Scans 2, 4, 6, ...
Avg	1116.96 Hz	1373.55	

Doppler and range rate values are related by

9.604 Hz/knot at 2.8 GHz.

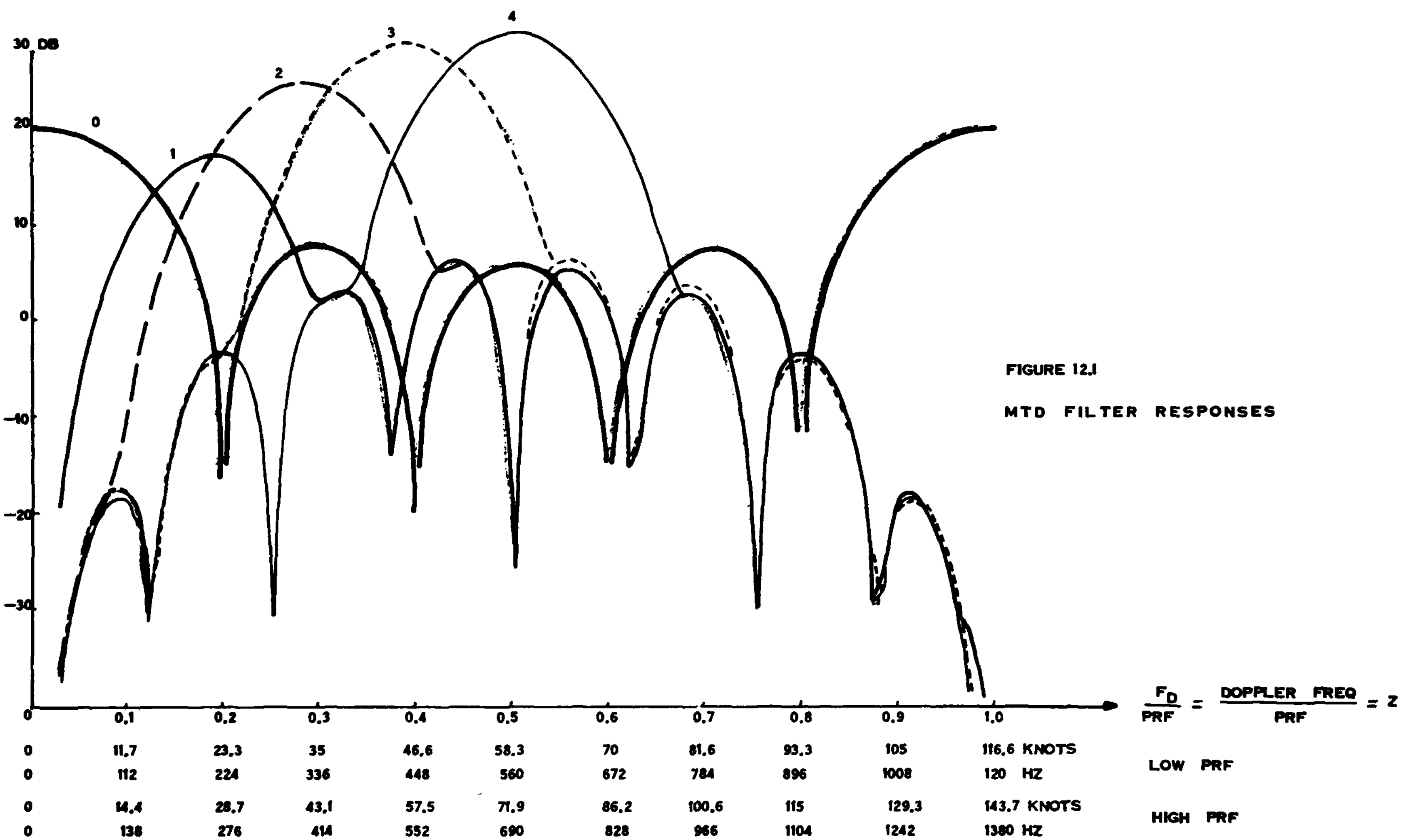


FIGURE 12.1

MTD FILTER RESPONSES

Lo PRF ↓ / Hi PRF → Doppler Filter No.	1	2	3	4	5	6	7	8,0
1	17.3-26.8	-97.2-(-102.3)	479.5-492.2 -89.6-(-97.2)	363.1-366.3 -206.3-(-218.6)	366.3-375.8 -205.9-(-206.3) -332-(-335)	246.8-253.3 -322-(-332)	253.3-259.5 -447-(-451)	14.1-17.3 130.4-143.1 -439-(-447)
2	26.8-32.9 -544-(-555)	32.9-37.4 - - -	492.2-492.5 -80-(-89.6)	492.5-502.8 -79.0-(-80)	375.8-383.4 -195.3-(-205.9)	383.4-386.4 -319-(-322)	259.5-268.9 -312-(-319)	143.1-153.8 268.9-270.1 -428-(-439)
3	160.4-167.7 -540-(-544)	37.4-45.9 -530-(-540)	45.9-51.4 - - -	502.8-509.4 -65-(79.0)	509.4-516.8 -189.0-(-195.3)	386.4-396.4 -181.4-(-189.0)	396.4-400.4 -304-(-312)	153.8-160.4 270.1-284.1 -297.7-(-304) -414-(-428)
4	167.7-176.0 -400-(-412)	176.0-181.4 -527-(-530)	51.4-63.1 -517-(-527)	63.1-65. -63.1-(-65)	516.8-526.6 -51.4-(-63.1)	526.6-530.4 -176.0-(-181.4)	400.4-412 -167.7-(-176.0)	284.1-297.7 412.-414 -284-(-297.7) -412-(-414)
5	303.5-311.7 (-396)-(-400)	181.4-189.1 -386-(-396)	189.1-195.3 -509-(-517)	65.-79. -503-(-509)	-45.9-(-51.4)	530.4-539.6 -37.4-(-45.9)	539.6-544.4 -160.4-(-167.7)	297.7-303.5 414.-428.0 -153.8-(-160.4) -270.1-(-284)
6	311.7-319.2 -259.5-(-268.9)	319.2-322.3 -383-(-386)	195.3-205.9 -376-(-383)	79.-80. -492.5-(-503)	80.-89.6 -492-(-492.5)	-32.9-(-37.4)	544.4-555.1 -26.8-(-32.9)	428.0-438.7 -143.1-(-153.8) -268.9-(-270.1)
7	446.7-451.3 -253.3-(-259.5)	322.3-332.2 -246.8-(-253.3)	205.9-206.3 332.2-335 -366-(-376)	206.3-218.6 -363-(-366)	89.6-97.2 -479-(-492)	97.2-102.3 - - -	-17.3-(-26.8)	438.7-446.7 -14.1-(-17.3) -130.4-(-143.1)
8,0	451.3-462.3 -110.2-(-125.7)	462.3-475.3 -102.3-(-110.2) -240.3-(-246.8)	335-349.4 475.3-479.5 -223.1-(-232.7) -232.7-(-240.3)	218.6-223.1 349.4-363.1 -218.6-(-223.1) -349-(-363)	223.1-240.3 -335-(-349) -475-(-479)	102.3-110.2 240.3-246.8 -462-(-475)	110.2-125.7 -451-(-462)	125.7-130.4 0-14.1 0-(-14.1) -125.7-(-130.4)

TABLE 12.1 DOPPLER RANGE RATE TABLE (KNOTS)

Sign Convention: + incoming aircraft
- outbound aircraft

The filters of Figure 12.1 are periodic with z periodicity equal to 1. The large prf change between alternate CPI's partially resolves this doppler ambiguity for FAA aircraft range rates of interest. Peak responses of the 8 doppler filters and the z values at which these peaks occur are as follows:

Filter #	Peak Response (dB)	z at Peak Response
0	20.00	.00
1	17.28	.18
2	25.00	.28
3	28.84	.38
4	30.10	.50
5	28.84	.62
6	25.00	.72
7	17.28	.82

Since each doppler filter has a different gain as a result of the MTI filter preceding the FFT, it is necessary to normalize the amplitudes at the output of the doppler filters. The above numbers lead to the following normalization table for signal strength (amplitude):

Filter #	Normalization Factor
0	1.0
1	.731
2	1.7782
3	2.766
4	3.20
5	2.766
6	1.7782
7	.731

The normalized strength is obtained by taking the strength of the doppler filter output (assuming a threshold crossing has taken place) and dividing by the normalization factor for that particular doppler filter. When this is accomplished, which in essence makes the filter peaks equal in amplitude, the filters are found to cross over at the following z values:

Filter Crossing	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
z*	0.121	0.23	0.321	0.441	0.559	0.679	0.77	0.879

Thus filters 1 and 2, when normalized, crossover at $z = z^* = 0.23$. Using these z^* values two tables were constructed of the doppler frequency coverage of each filter at the average low and average high prf. The filter with the maximum normalized output within a doppler frequency range was considered to be the filter covering that frequency range. Combining the results of these two tables, and using the relationship between range rate and doppler frequency, Table 12.1 was constructed. Table 11.2 was derived from Table 12.1 by tabulating the mid-points of values in 12.1.

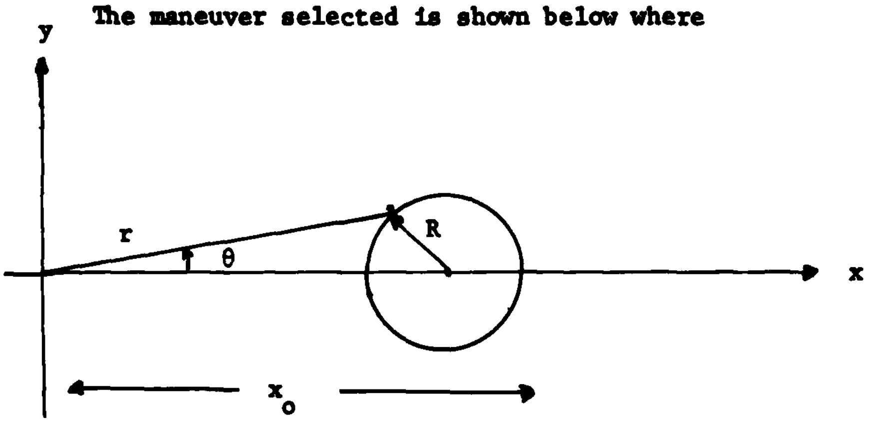
To illustrate, consider the case where filter i had the maximum normalized doppler filter output at the low prf between doppler frequencies of 100 Hz and 200 Hz. Also, consider the case where filter j had the maximum normalized doppler filter output at the high prf between doppler frequencies of 125 Hz and 250 Hz. For this hypothetical case the i, j combination handles the overlapping range from 125 Hz to 200 Hz or 13 knots to 20.8 knots. This data would thus be entered into Table 12.1.

12.2 MTD Simulation of Maneuvering Target

A tracking simulation of a circularly maneuvering target was implemented to ascertain the differences in instantaneous doppler and tracker range rate which can be anticipated due to tracker lag and noise. This was done to bound doppler and tracker range rate differences which would be acceptable in the doppler decoding process. Also as an initial exploration as to the potential usefulness of the MTD doppler data in improving tracker performance, the doppler data was used to rate-aid the tracker in the simulation. The mean and standard deviation of the range rate errors, with and without rate aiding, were calculated and indicate a significant reduction in the tracker errors when doppler data is used to rate-aid the tracker.

Doppler, Tracker Range Date Differences

The maneuver selected is shown below where



the x and y coordinates of the target without noise are

$$x = x_o + R \cos wt$$

$$y = R \sin wt$$

Range and bearing noise of amounts σ_r = .018 nmi and σ_θ = 0.28° were added to the range and bearing measurements and the resultant x and y coordinates were tracked with constant gains α, β tracking filters. The filter gains were selected to be the same for the x and y coordinates and a 4 second scan time was assumed. With the radius R of the maneuver equal to 1 nmi and w = .0526 radians/second (corresponding to a 188 knot aircraft with a physical acceleration of 0.58 g's) the range rate errors are shown in Table 12.2 where averages over 30 scans of the trajectory have been used.

The range rate error at each scan is given by

$$\Delta\dot{R} = \dot{R}_{Tracker} - \dot{R}_{doppler} \qquad (12.3)$$

where

$$\dot{R}_{tracker} = (\hat{x}\,\hat{\dot{x}} + \hat{y}\,\hat{\dot{y}}) \Big/ \sqrt{\hat{x}^2 + \hat{y}^2} \text{ and}$$

$$\dot{R}_{doppler} = -\,Rw\,x_o \sin wt \Big/ \sqrt{x_o^{\,2} + R^2 + 2R\,x_o \cos wt}$$

$\hat{x}$, $\hat{y}$, $\hat{\dot{x}}$, $\hat{\dot{y}}$ are tracker derived position and rate components.

X_o, R, W specify the true target coordinates.

The tracker equations are as follows where ^ ~ correspond to filtered and predicted quantities, respectively

$$\hat{x}(n) = \tilde{x}(n) + \alpha[\mathring{x}(n) - \tilde{x}(n)]$$

$$\hat{\dot{x}}(n) = \tilde{\dot{x}}(n) + \frac{\beta}{\Delta t}[\mathring{x}(n) - \tilde{x}(n)]$$

$$\hat{y}(n) = \tilde{y}(n) + \alpha[\mathring{y}(n) - \tilde{y}(n)] \qquad (12.4)$$

$$\hat{y}(n) = \tilde{\dot{y}}(n) + \frac{\beta}{\Delta t}[\mathring{y}(n) - \tilde{y}(n)]$$

$$\hat{\hat{\dot{x}}}(n) = \hat{\dot{x}}(n) + G[\dot{r}\cos\Theta - \hat{\dot{x}}(n)]$$

$$\hat{\hat{\dot{y}}}(n) = \hat{\dot{y}}(n) + H[\dot{r}\sin\Theta - \hat{\dot{y}}(n)]$$

$$\tilde{x}(n) = \hat{x}(n-1) + \hat{\dot{x}}(n-1)\cdot\Delta t \qquad (12.5)$$

$$\tilde{y}(n) = \hat{y}(n-1) + \hat{\dot{y}}(n-1)\cdot\Delta t$$

$$\tilde{\dot{x}}(n) = \hat{\dot{x}}(n-1)$$

$$\tilde{\dot{y}}(n) = \hat{\dot{y}}(n-1)$$

TABLE 12.2

TRACKER $\dot{R}$ ERRORS, WITH AND WITHOUT RATE AIDING

X_o	α	β	G	H	Noise	Mean $\Delta\dot{R}$ Error (Knots)	σ of $\Delta\dot{R}$ Error (Knots)	
50	1	1	0.5	0.5	Yes	-.647	12.28	2:1
50	1	1	0	0	Yes	-1.29	24.56	
50	1	1	0	0	No	-1.19	13.39	
50	.7	.377	0.5	0.5	Yes	-1.04	13.54	2.76:1
50	.7	.377	0	0	Yes	-3.24	37.4	
50	.7	.377	0	0	No	-3.27	37.0	
50	.5	.1667	0.5	0.5	Yes	-1.42	17.62	3.75:1
50	.5	.1667	0	0	Yes	-8.07	66.15	
50	.5	.1667	0.5	0.5	No	-1.40	17.55	
50	.3	.0529	0.5	0.5	Yes	-1.99	21.87	5.1:1
50	.3	.0529	0	0	Yes	-27.35	111.73	
20	1	1	0.5	0.5	Yes	-.66	12.26	
20	.7	.377	0.5	0.5	Yes	-.88	13.57	
20	.5	.1667	0.5	0.5	Yes	-1.24	17.71	

The last two equations of 12.4 correspond to rate-aiding equations for tracking where a further refinement of the rate terms is accomplished with the doppler measurement $\dot{r}$ and the target bearing θ. The tracker gains for this purpose are defined as G and H.

Table 12.2 indicates that with G = H = 0 (no rate aiding) the mean and standard deviation of the $\Delta\dot{R}$ error are as follows as a function of tracker α, β values:

α	β	$<\Delta\dot{R}>$	$\sigma_{\Delta\dot{R}}$
1	1	-1.29 knots	24.56 knots
.7	.377	-3.24	37.4
.5	.1667	-8.07	66.15
.3	.0529	-27.35	111.73

Table 12.2 also indicates that the difference between noise and no-noise without rate-aiding, is only significant at the tabulated values $\alpha = \beta = 1$. Also indicated is the fact that the $\dot{R}$ errors are independent of the location of the center of the maneuver as long as $x_o << R$. This can be inferred from Equation 12.3.

Based upon the numbers presented here and the tracker gains of the APL ASR tracker a $\Delta\dot{R}$ = ±50 knots was selected as an acceptable limit for the doppler decoding process described in Section 11.2.

Rate-Aided Tracking

The last two equations of 12.4 were implemented to assess improvements which can be achieved by rate aiding the tracking. The results are indicated in Table 12.2 where G = H = 0.5 were selected as the rate-aiding gains. Numerical results indicate that rate-aiding reduces the sigma of the $\Delta\dot{R}$ error anywhere from a factor of 2:1 to 5.1:1 as the α, β values of the x, y tracker are reduced from 1, 1 to .3, 0.0529. For instance, for the low α, β values (.3, 0.0529), $\sigma_{\Delta\dot{R}}$ is reduced from 111.73 knots to 21.87 knots when raid-aiding is used. Note this procedure is not optimal or even a recommended procedure but was used to indicate the potential for improvement in track quality to be achieved via using doppler data. Further doppler data was available for every update so that missed doppler logic has not been considered.

12.3 Spectral Purity

A method was developed to determine the spectral purity of the MTD returns in a range-azimuth cell (RAC) to help ascertain the quality of the doppler data. This was accomplished via use of the VRS word amplitudes in a RAC and the known frequency response of each of the 8 MTD filters. The measure used for spectral purity is given by the following equation:

$$R(z) = \sum_{i \neq i\ max} \left(\frac{\mathring{A}_i}{\mathring{A}_{i\ max}} - \frac{A_i^t\ (z)}{A_{i\ max}^t(z)} \right)^2 \qquad \text{where}$$

$\mathring{A}_{i\ max}$ = measured amplitude of the VRS word with maximum amplitude

$A_{i\ max}^t\ (z)$ = theoretical amplitude of maximum amplitude VRS word which is a function of z = target doppler frequency divided by transmitter PRF (pulse repetition frequency)

$A_i^t\ (z)$ = theoretical amplitudes of other VRS words

Z is varied through a range of values corresponding to the frequency coverage of the doppler filter with maximum amplitude. Ten values of z are more than sufficient with a separation of $\Delta z = .01$. This value provides a range rate resolution between 1 or 1.5 knots depending upon the prf. When the z value is found such that R(z) is a minimum then the magnitude R_{min} (z) is an indication of the spectral purity of the MTD returns. If $R_{min}(z) < 0.1$ then a good match has been achieved between measured and theoretical responses and it can be said that the target is emitting a single spectral line. For $R_{min}(z) > 0.1$ a multiple line emitting target is likely.

Numerical Examples

This technique was applied to a limited number of MTD responses and an example of each type of spectral purity is given here.

Scan # 1349 from Tape 12248
CPI Bearing = 263.58° CPI PRF = 1

Doppler Filter No.	Range (nmi)	Amplitude
0	35.5	20
1	35.5	11
2	35.5	140
3	35.5	77
6	35.5	13
7	35.5	7

$z = z_{min} = 0.29$ $\qquad R_{min}\ (0.29) = .0084$

Scan # 1338 from Tape 12248
CPI Bearing = 265.08°   CPI PRF = 3

Doppler Filter No.	Range (nmi)	Amplitude
1	42.3125	30
2	42.3125	78
3	42.3125	19
5	42.3125	28
6	42.3125	11
7	42.3125	5

$z = z_{min} = 0.24$ $R_{min}\ (0.24) = .16$

In the first example 6 VRS words were obtained at the range and azimuth indicated. Application of the equation for R(z) indicates a best match at $z = 0.29$ where $R_{min}\ (0.29) = .0084$. This corresponds to a spectrally pure return (one single spectral line). In the second example 6 VRS words were again obtained and a best match was obtained at $z = 0.24$ where R $R_{min}\ (0.24) = 0.16$. This corresponds to a target emitting multiple spectral lines.

It was desired to apply this technique to MTD reports from Firm Tracks as output by the tracker (Section 11). The objective was to see if jets and propeller aircraft can be classified via this technique and to eliminate erroneous doppler velocity computation caused by broad spectral returns. It would also be of interest to see if there is a correlation between the spectral purity results and the frequency of generation of false doppler reports from the doppler decoding technique. Unfortunately, this task was not completed due to time limitations.

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8. "Design Data for Moving Target Detector", UNIVAC ATC 12900, March 1976

GLOSSARY

Digitizer - That interface between the analog radar system and the digital computer system which extracts target information from the analog video and develops digital reports for subsequent processing.

MTD - Moving Target Detector. A digitizer developed by Lincoln Laboratory for use with the FAA ASR primary radars. Utilizes modifications in the radar system to extract doppler and amplitude information as well as positional data.

VRS Word - Velocity (V), Range (R), and Strength (S) or amplitude word developed by MTD upon detection of a target by a doppler filter.

PAZ Word - PRF (P) and Azimuth word generated by MTD. Indicates PRF and azimuth of following VRS words.

CPI - Coherent (C) Processing (P) Interval (I). Consists of 10 (ten) consecutive pulses of data in azimuth. PRF is maintained constant over this interval and data in this interval is combined by MTD to produce target reports.

Primitive Reports - Generic name for the reports (VRS and PAZ) generated by MTD.

Primitive Target - Consists of all the VRS words in one range azimuth cell.

Centroider - That algorithm which combines all the VRS words generated by MTD for one target into a single report for use in tracking and display functions.

Tracker - That algorithm which utilizes the scan to scan properties of the centroids generated by the MTD primitive reports to extract moving targets and suppress clutter.

APPENDIX A

CENTROID STATISTICS

Run 1 - All Centroids

NUMBER OF CENTROIDS=19988

RANGE OF CENTROID

RANGE	NUMBER	PERCENT
< 0.5	24	0.0
< 1.0	56	0.3
< 2.0	191	0.9
< 4.0	965	4.8
< 8.0	2150	10.8
<16.0	7742	38.6
<32.0	7905	39.5
≥32.0	955	4.8

MAX SN OF CENTROID

MAX SN	NUMBER	PERCENT
< 8	5911	29.5
< 16	5467	27.3
< 24	2329	11.6
< 32	1502	7.5
< 40	1057	5.3
< 48	736	3.6
< 56	583	2.9
< 64	342	1.6
< 72	315	1.5
< 80	254	1.3
< 88	200	1.0
< 96	172	0.8
<104	164	0.8
<112	133	0.6
<120	70	0.3
<128	92	0.4
<136	78	0.4
<144	67	0.3
<152	54	0.3
<160	56	0.3
<168	40	0.1
<176	37	0.1
<184	30	0.1
<192	33	0.1
<200	20	0.0
<208	28	0.1
<216	17	0.0
<224	18	0.0
<232	10	0.0
<240	16	0.0
<248	16	0.0
<256	11	0.0
<264	12	0.0
<272	4	0.0
<280	11	0.0
<288	9	0.0
<296	8	0.0
<304	10	0.0
<312	9	0.0
<320	13	0.0
<328	2	0.0
<336	6	0.0
<344	2	0.0
<352	4	0.0
<360	7	0.0
<368	5	0.0
<376	5	0.0
<384	3	0.0
<392	2	0.0
<400	3	0.0
<408	2	0.0
<416	2	0.0
<424	0	0.0
<432	1	0.0
<440	1	0.0
<448	0	0.0
<456	0	0.0
<464	0	0.0
<472	0	0.0
<480	0	0.0

Run 7 - All Centroids

NUMBER OF CENTROIDS=10410

RANGE OF CENTROID

RANGE	NUMBER	PERCENT
< 0.5	4	0.0
< 1.0	28	0.3
< 2.0	142	1.3
< 4.0	880	8.4
< 8.0	4495	43.1
<16.0	3680	35.3
<32.0	804	7.6
≥32.0	377	3.5

MAX SN OF CENTROID

MAX SN	NUMBER	PERCENT
< 8	2933	28.1
< 16	5227	50.1
< 24	1179	11.3
< 32	376	3.5
< 40	231	2.1
< 48	151	1.4
< 56	82	0.8
< 64	65	0.5
< 72	41	0.4
< 80	31	0.3
< 88	24	0.1
< 96	10	0.0
<104	7	0.0
<112	9	0.0
<120	8	0.0
<128	5	0.0
<136	2	0.0
<144	5	0.0
<152	3	0.0
<160	3	0.0
<168	6	0.0
<176	2	0.0
<184	0	0.0
<192	0	0.0
<200	1	0.0
<208	1	0.0
<216	2	0.0
<224	2	0.0
<232	1	0.0
<240	0	0.0
<248	0	0.0
<256	0	0.0
<264	1	0.0
<272	1	0.0
<280	0	0.0
<288	0	0.0
<296	0	0.0
<304	0	0.0
<312	1	0.0
<320	0	0.0
<328	0	0.0
<336	0	0.0
<344	0	0.0
<352	0	0.0
<360	0	0.0
<368	0	0.0
<376	0	0.0
<384	0	0.0
<392	0	0.0
<400	0	0.0
<408	0	0.0
<416	0	0.0
<424	0	0.0
<432	0	0.0
<440	0	0.0
<448	0	0.0
<456	0	0.0
<464	0	0.0
<472	0	0.0
<480	0	0.0

Run 1 - All Centroids

<488	0	0.0
<496	0	0.0
<504	0	0.0
<512	0	0.0
≥512	9	0.0

NO OF FILTERS RUNG

FILTERS	NUMBER	PERCENT
1	12972	64.9
2	2944	14.6
3	1052	5.3
4	584	2.9
5	350	1.8
6	237	1.1
7	158	0.8
8	159	0.8
9	125	0.6
10	118	0.5
11	102	0.5
12	100	0.5
13	95	0.4
14	73	0.3
15	78	0.4
16	58	0.3
17	56	0.3
18	49	0.1
19	41	0.1
20	43	0.1
21	38	0.1
22	48	0.1
23	38	0.1
24	38	0.1
25	28	0.1
26	26	0.1
27	23	0.0
28	27	0.1
29	23	0.0
30	23	0.0
31	23	0.0
32	18	0.0
33	18	0.0
34	21	0.0
35	21	0.0
36	21	0.0
37	21	0.0
38	15	0.0
39	12	0.0
40	8	0.0
41+	104	0.5

NO OF AZIMUTHS

AZIMUTHS	NUMBER	PERCENT
1	15722	78.6
2	2416	12.0
3	1070	5.3
4	546	2.6
5	166	0.8
6	51	0.3
7	10	0.0
8+	7	0.0

TOTAL RANGE BINS

RANGE BINS	NUMBER	PERCENT
1	14146	70.8
2	3070	15.3
3	837	4.1
4	534	2.6
5	320	1.5
6	443	2.1
7	222	1.0
8	210	1.0
9	78	0.4
10	64	0.3
11+	64	0.3

Run 7 - All Centroids

<488	0	0.0
<496	0	0.0
<504	0	0.0
<512	0	0.0
≥512	0	0.0

NO OF FILTERS RUNG

FILTERS	NUMBER	PERCENT
1	5241	50.3
2	2149	20.6
3	1138	10.9
4	675	6.4
5	433	4.1
6	266	2.5
7	161	1.5
8	108	1.0
9	65	0.5
10	54	0.5
11	29	0.3
12	20	0.1
13	24	0.1
14	15	0.1
15	6	0.0
16	4	0.0
17	7	0.0
18	3	0.0
19	4	0.0
20	3	0.0
21	2	0.0
22	0	0.0
23	1	0.0
24	2	0.0
25	0	0.0
26	0	0.0
27	0	0.0
28	0	0.0
29	0	0.0
30	0	0.0
31	0	0.0
32	0	0.0
33	0	0.0
34	0	0.0
35	0	0.0
36	0	0.0
37	0	0.0
38	0	0.0
39	0	0.0
40	0	0.0
41+	0	0.0

NO OF AZIMUTHS

AZIMUTHS	NUMBER	PERCENT
1	6627	63.6
2	2738	26.3
3	791	7.5
4	211	2.0
5	36	0.3
6	7	0.0
7	0	0.0
8+	0	0.0

TOTAL RANGE BINS

RANGE BINS	NUMBER	PERCENT
1	5822	55.9
2	2489	23.9
3	924	8.9
4	642	6.1
5	255	2.4
6	155	1.4
7	74	0.6
8	31	0.3
9	10	0.0
10	5	0.0
11+	3	0.0

Run 1 - All Centroids

FREQUENCY OF EVEN FILTER

FILTER NO	NUMBER	PERCENT
0	737	3.6
1	3518	17.5
2	3259	16.3
3	1283	6.4
4	829	4.1
5	649	3.1
6	1247	6.1
7	1581	7.9

FREQUENCY OF ODD FILTER

FILTER NO	NUMBER	PERCENT
0	651	3.3
1	2952	14.8
2	2440	12.1
3	869	4.3
4	741	3.6
5	587	2.9
6	923	4.5
7	1506	7.5

MAX FILTER COUNT IN ANY RANGE CELL

FILTER COUNT	NUMBER	PERCENT
1	15557	77.8
2	2357	11.8
3	557	2.8
4	328	1.6
5	322	1.5
6	320	1.5
7	283	1.4
8	264	1.3

RANGE EXTENT OF CENTROID

RANGE EXTENT	NUMBER	PERCENT
1	15901	79.5
2	3877	19.4
3	210	1.0
4	0	0.0
5	0	0.0
> 5	0	0.0

RATIO OF MAX SN TO MIN SN

RATIO	NUMBER	PERCENT
< 1	0	0.0
< 2	2704	73.8
< 3	583	15.9
< 4	166	4.5
< 5	81	2.1
< 6	29	0.8
> 6	98	2.6

NUMBER OF CENTROIDS WITH EVEN-ODD DATA= 3661

RATIO FILTERS RUNG TO TOTAL RANGE BINS

RATIO	NUMBER	PERCENT
< 2	16942	84.8
< 3	1831	9.1
< 4	579	2.9
< 5	339	1.6
< 6	176	0.9
< 7	78	0.4
< 8	32	0.1
< 9	11	0.0

FLAGS

Run 7 - All Centroids

FREQUENCY OF EVEN FILTER

FILTER NO	NUMBER	PERCENT
0	253	2.4
1	2539	24.4
2	2569	24.6
3	487	4.6
4	123	1.1
5	84	0.8
6	318	3.0
7	1229	11.8

FREQUENCY OF ODD FILTER

FILTER NO	NUMBER	PERCENT
0	322	3.0
1	3145	30.1
2	1407	13.5
3	148	1.4
4	159	1.5
5	73	0.6
6	175	1.6
7	1041	10.0

MAX FILTER COUNT IN ANY RANGE CELL

FILTER COUNT	NUMBER	PERCENT
1	7693	73.9
2	2417	23.1
3	171	1.6
4	55	0.5
5	71	0.6
6	3	0.0
7	0	0.0
8	0	0.0

RANGE EXTENT OF CENTROID

RANGE EXTENT	NUMBER	PERCENT
1	7826	75.1
2	2532	24.3
3	49	0.4
4	3	0.0
5	0	0.0
> 5	0	0.0

RATIO OF MAX SN TO MIN SN

RATIO	NUMBER	PERCENT
< 1	0	0.0
< 2	3079	85.1
< 3	417	11.5
< 4	65	1.8
< 5	23	0.6
< 6	16	0.4
> 6	16	0.4

NUMBER OF CENTROIDS WITH EVEN-ODD DATA= 3616

RATIO FILTERS RUNG TO TOTAL RANGE BINS

RATIO	NUMBER	PERCENT
< 2	9536	91.5
< 3	733	7.0
< 4	53	0.5
< 5	32	0.3
< 6	55	0.5
< 7	1	0.0
< 8	0	0.0
< 9	0	0.0

FLAGS

Run 1 - All Centroids

```
FLAG 1 SET=13103  PERCENT= 65.5
FLAG 2 SET=10669  PERCENT= 53.4
FLAGS 1 AND 2 SET= 3784  PERCENT= 18.9
FLAG 3 SET=    71  PERCENT=  0.3
FLAG 4 SET=    59  PERCENT=  0.3
FLAG 8 SET=   121  PERCENT=  0.5
FLAG10 SET=   263  PERCENT=  1.3

AVERAGE CENTROIDS PER SCAN= 60.5
```

Run 7 - All Centroids

```
FLAG 1 SET= 7602  PERCENT= 73.0
FLAG 2 SET= 6470  PERCENT= 62.1
FLAGS 1 AND 2 SET= 3662  PERCENT= 35.1
FLAG 3 SET=    39  PERCENT=  0.3
FLAG 4 SET=    16  PERCENT=  0.1
FLAG 8 SET=    20  PERCENT=  0.1
FLAG10 SET=   138  PERCENT=  1.3
```

CENTROID STATISTICS

Run 1 - Firm Track Centroids Only

NUMBER OF CENTROIDS= 1938

RANGE OF CENTROID

RANGE	NUMBER	PERCENT
< 0.5	0	0.0
< 1.0	0	0.0
< 2.0	11	0.5
< 4.0	62	3.1
< 8.0	193	9.9
<16.0	562	28.9
<32.0	963	49.6
≥32.0	147	7.5

MAX SN OF CENTROID

MAX SN	NUMBER	PERCENT
< 8	66	3.4
< 16	279	14.4
< 24	217	11.1
< 32	193	9.9
< 40	182	9.4
< 48	135	6.9
< 56	105	5.4
< 64	82	4.1
< 72	78	4.0
< 80	59	3.0
< 88	68	1.5
< 96	43	2.1
<104	49	2.5
<112	33	1.6
<120	25	1.3
<128	29	1.4
<136	21	1.0
<144	23	1.1
<152	19	0.9
<160	15	0.8
<168	17	0.9
<176	17	0.9
<184	12	0.5
<192	20	1.0
<200	11	0.5
<208	13	0.6
<216	7	0.3
<224	4	0.1
<232	3	0.1
<240	13	0.6
<248	8	0.4
<256	6	0.3
<264	10	0.5
<272	3	0.1
<280	5	0.3
<288	6	0.3
<296	6	0.3
<304	6	0.3
<312	7	0.3
<320	10	0.5
<328	1	0.0
<336	6	0.3
<344	2	0.0
<352	3	0.1
<360	5	0.3
<368	5	0.3
<376	3	0.1
<384	3	0.1
<392	0	0.0
<400	2	0.0
<408	1	0.0
<416	0	0.0
<424	0	0.0
<432	1	0.0
<440	1	0.0
<448	0	0.0
<456	0	0.0
<464	0	0.0
<472	0	0.0
<480	0	0.0

Run 7 - Firm Track Centroids Only

NUMBER OF CENTROIDS= 121

RANGE OF CENTROID

RANGE	NUMBER	PERCENT
< 0.5	0	0.0
< 1.0	0	0.0
< 2.0	0	0.0
< 4.0	5	4.1
< 8.0	67	55.3
<16.0	9	7.4
<32.0	40	33.0
≥32.0	0	0.0

MAX SN OF CENTROID

MAX SN	NUMBER	PERCENT
< 8	10	8.3
< 16	77	63.6
< 24	29	23.9
< 32	2	1.6
< 40	1	0.8
< 48	2	1.6
< 56	0	0.0
< 64	0	0.0
< 72	0	0.0
< 80	0	0.0
< 88	0	0.0
< 96	0	0.0
<104	0	0.0
<112	0	0.0
<120	0	0.0
<128	0	0.0
<136	0	0.0
<144	0	0.0
<152	0	0.0
<160	0	0.0
<168	0	0.0
<176	0	0.0
<184	0	0.0
<192	0	0.0
<200	0	0.0
<208	0	0.0
<216	0	0.0
<224	0	0.0
<232	0	0.0
<240	0	0.0
<248	0	0.0
<256	0	0.0
<264	0	0.0
<272	0	0.0
<280	0	0.0
<288	0	0.0
<296	0	0.0
<304	0	0.0
<312	0	0.0
<320	0	0.0
<328	0	0.0
<336	0	0.0
<344	0	0.0
<352	0	0.0
<360	0	0.0
<368	0	0.0
<376	0	0.0
<384	0	0.0
<392	0	0.0
<400	0	0.0
<408	0	0.0
<416	0	0.0
<424	0	0.0
<432	0	0.0
<440	0	0.0
<448	0	0.0
<456	0	0.0
<464	0	0.0
<472	0	0.0
<480	0	0.0

Run 1 - Firm Track Centroids Only

<488	0	0.0
<496	0	0.0
<504	0	0.0
<512	0	0.0
≥512	0	0.0

NO OF FILTERS RUNG

FILTERS	NUMBER	PERCENT
1	123	6.3
2	144	7.4
3	99	5.0
4	101	5.1
5	85	4.4
6	81	4.1
7	69	3.5
8	89	4.5
9	73	3.8
10	74	3.8
11	64	3.3
12	70	3.5
13	67	3.4
14	55	2.8
15	62	3.1
16	46	2.3
17	47	2.4
18	45	2.3
19	35	1.8
20	36	1.8
21	33	1.6
22	32	1.6
23	33	1.6
24	29	1.4
25	24	1.1
26	18	0.9
27	19	0.9
28	21	1.0
29	17	0.9
30	20	1.0
31	18	0.9
32	15	0.8
33	14	0.6
34	16	0.8
35	18	0.9
36	11	0.5
37	16	0.8
38	12	0.5
39	12	0.5
40	6	0.3
41+	89	4.5

NO OF AZIMUTHS

AZIMUTHS	NUMBER	PERCENT
1	279	14.4
2	432	22.3
3	659	34.0
4	406	20.9
5	116	5.9
6	34	1.8
7	9	0.4
8+	3	0.1

TOTAL RANGE BINS

RANGE BINS	NUMBER	PERCENT
1	186	9.5
2	241	12.4
3	211	10.9
4	245	12.6
5	213	10.9
6	346	17.8
7	173	8.9
8	165	8.5
9	59	3.0
10	52	2.6
11+	47	2.4

Run 7 - Firm Track Centroids Only

<488	0	0.0
<496	0	0.0
<504	0	0.0
<512	0	0.0
>512	0	0.0

NO OF FILTERS RUNG

FILTERS	NUMBER	PERCENT
1	53	43.8
2	42	34.6
3	13	10.6
4	8	6.5
5	3	2.4
6	1	0.8
7	1	0.8
8	0	0.0
9	0	0.0
10	0	0.0
11	0	0.0
12	0	0.0
13	0	0.0
14	0	0.0
15	0	0.0
16	0	0.0
17	0	0.0
18	0	0.0
19	0	0.0
20	0	0.0
21	0	0.0
22	0	0.0
23	0	0.0
24	0	0.0
25	0	0.0
26	0	0.0
27	0	0.0
28	0	0.0
29	0	0.0
30	0	0.0
31	0	0.0
32	0	0.0
33	0	0.0
34	0	0.0
35	0	0.0
36	0	0.0
37	0	0.0
38	0	0.0
39	0	0.0
40	0	0.0
41+	0	0.0

NO OF AZIMUTHS

AZIMUTHS	NUMBER	PERCENT
1	77	63.6
2	39	32.1
3	5	4.1
4	0	0.0
5	0	0.0
6	0	0.0
7	0	0.0
8+	0	0.0

TOTAL RANGE BINS

RANGE BINS	NUMBER	PERCENT
1	57	47.0
2	45	37.1
3	8	6.5
4	9	7.4
5	2	1.6
6	0	0.0
7	0	0.0
8	0	0.0
9	0	0.0
10	0	0.0
11+	0	0.0

Run 1 - Firm Track Centroids Only

FREQUENCY OF EVEN FILTER

FILTER NO	NUMBER	PERCENT
0	270	13.9
1	226	11.6
2	231	11.9
3	203	10.4
4	196	10.0
5	229	11.8
6	258	13.3
7	176	9.0

FREQUENCY OF ODD FILTER

FILTER NO	NUMBER	PERCENT
0	166	8.5
1	272	14.0
2	319	16.4
3	266	13.6
4	165	8.5
5	217	11.1
6	173	8.9
7	184	9.4

MAX FILTER COUNT IN ANY RANGE CELL

FILTER COUNT	NUMBER	PERCENT
1	274	14.1
2	402	20.6
3	276	14.1
4	213	10.9
5	188	9.6
6	204	10.5
7	190	9.8
8	191	9.8

RANGE EXTENT OF CENTROID

RANGE EXTENT	NUMBER	PERCENT
1	414	21.3
2	1381	71.3
3	143	7.4
4	0	0.0
5	0	0.0
> 5	0	0.0

RATIO OF MAX SN TO MIN SN

RATIO	NUMBER	PERCENT
< 1	0	0.0
< 2	1278	82.9
< 3	183	11.9
< 4	38	2.4
< 5	16	1.0
< 6	5	0.3
> 6	20	1.3

NUMBER OF CENTROIDS WITH EVEN-ODD DATA= 1540

RATIO FILTERS RUNG TO TOTAL RANGE BINS

RATIO	NUMBER	PERCENT
< 2	678	34.9
< 3	615	31.6
< 4	338	17.4
< 5	194	10.0
< 6	76	3.9
< 7	27	1.4
< 8	10	0.5
< 9	0	0.0

DOT-RDOT STATISTICS,NO RESTRICTIONS

Run 7 - Firm Track Centroids Only

FREQUENCY OF EVEN FILTER

FILTER NO	NUMBER	PERCENT
0	3	2.4
1	61	50.4
2	10	8.3
3	4	3.3
4	0	0.0
5	1	0.8
6	3	2.4
7	13	10.6

FREQUENCY OF ODD FILTER

FILTER NO	NUMBER	PERCENT
0	1	0.8
1	45	37.1
2	9	7.4
3	0	0.0
4	0	0.0
5	0	0.0
6	0	0.0
7	15	12.4

MAX FILTER COUNT IN ANY RANGE CELL

FILTER COUNT	NUMBER	PERCENT
1	105	86.8
2	16	13.1
3	0	0.0
4	0	0.0
5	0	0.0
6	0	0.0
7	0	0.0
8	0	0.0

RANGE EXTENT OF CENTROID

RANGE EXTENT	NUMBER	PERCENT
1	84	69.4
2	35	28.9
3	2	1.6
4	0	0.0
5	0	0.0
> 5	0	0.0

RATIO OF MAX SN TO MIN SN

RATIO	NUMBER	PERCENT
< 1	0	0.0
< 2	37	86.0
< 3	6	13.9
< 4	0	0.0
< 5	0	0.0
< 6	0	0.0
> 6	0	0.0

NUMBER OF CENTROIDS WITH EVEN-ODD DATA= 43

RATIO FILTERS RUNG TO TOTAL RANGE BINS

RATIO	NUMBER	PERCENT
< 2	116	95.8
< 3	5	4.1
< 4	0	0.0
< 5	0	0.0
< 6	0	0.0
< 7	0	0.0
< 8	0	0.0
< 9	0	0.0

DOT-RDOT STATISTICS,NO RESTRICTIONS

Run 1 - Firm Track Centroids Only

DOT-RDOT	NUMBER	PERCENT
< 5	686	42.5
< 10	401	24.8
< 15	183	11.3
< 20	84	5.1
< 25	43	2.6
< 30	28	1.6
< 35	14	0.8
< 40	18	1.0
< 45	9	0.5
< 50	5	0.3
< 55	11	0.6
< 60	7	0.4
< 65	1	0.0
< 70	4	0.1
< 75	2	0.0
< 80	1	0.0
< 85	1	0.0
< 90	0	0.0
< 95	0	0.0
<100	1	0.0
<105	2	0.0
<110	2	0.0
<115	3	0.1
<120	4	0.1
<125	5	0.3
<130	6	0.3
<135	5	0.3
<140	8	0.4
<145	7	0.4
<150	4	0.1
<155	3	0.1
<160	2	0.0
<165	2	0.0
<170	2	0.0
<175	1	0.0
<180	2	0.0
<185	0	0.0
<190	0	0.0
<195	0	0.0
<200	0	0.0
<205	1	0.0
<210	3	0.1
<215	1	0.0
<220	0	0.0
<225	3	0.1
<230	6	0.3
<235	7	0.4
<240	5	0.3
<245	5	0.3
<250	1	0.0
≥250	24	1.4

MEAN= 22.0497

MEAN SQUARE= 3158.5248

STANDARD DEVIATION= 51.6875

CENTROIDS USED= 1613

DOT-RDOT STATISTICS,FLAG TEST

DOT-RDOT	NUMBER	PERCENT
< 5	650	44.4
< 10	382	26.1
< 15	167	11.4
< 20	81	5.5
< 25	38	2.5
< 30	24	1.6
< 35	14	0.9
< 40	18	1.1
< 45	7	0.4
< 50	4	0.3
< 55	10	0.6
< 60	6	0.4
< 65	1	0.0

Run 7 - Firm Track Centroids Only

DOT-RDOT	NUMBER	PERCENT
< 5	17	38.6
< 10	9	20.4
< 15	6	13.6
< 20	0	0.0
< 25	1	2.3
< 30	3	6.8
< 35	0	0.0
< 40	0	0.0
< 45	0	0.0
< 50	2	4.5
< 55	1	2.3
< 60	0	0.0
< 65	0	0.0
< 70	1	2.3
< 75	0	0.0
< 80	0	0.0
< 85	0	0.0
< 90	0	0.0
< 95	0	0.0
<100	0	0.0
<105	1	2.3
<110	1	2.3
<115	0	0.0
<120	0	0.0
<125	0	0.0
<130	0	0.0
<135	0	0.0
<140	0	0.0
<145	0	0.0
<150	0	0.0
<155	1	2.3
<160	0	0.0
<165	0	0.0
<170	0	0.0
<175	0	0.0
<180	0	0.0
<185	0	0.0
<190	0	0.0
<195	0	0.0
<200	0	0.0
<205	0	0.0
<210	0	0.0
<215	0	0.0
<220	0	0.0
<225	0	0.0
<230	0	0.0
<235	0	0.0
<240	0	0.0
<245	0	0.0
<250	0	0.0
≥250	1	2.3

MEAN= 32.0051

MEAN SQUARE= 8494.3490

STANDARD DEVIATION= 86.4219

CENTROIDS USED= 44

DOT-RDOT STATISTICS,FLAG TEST

DOT-RDOT	NUMBER	PERCENT
< 5	17	39.5
< 10	9	20.9
< 15	6	13.9
< 20	0	0.0
< 25	1	2.3
< 30	3	6.9
< 35	0	0.0
< 40	0	0.0
< 45	0	0.0
< 50	2	4.6
< 55	1	2.3
< 60	0	0.0
< 65	0	0.0

Run 1 - Firm Track Centroids Only

< 70	3	0.1
< 75	2	0.1
< 80	1	0.0
< 85	0	0.0
< 90	0	0.0
< 95	0	0.0
<100	0	0.0
<105	1	0.0
<110	2	0.1
<115	1	0.0
<120	2	0.1
<125	2	0.1
<130	3	0.1
<135	1	0.0
<140	7	0.4
<145	4	0.3
<150	2	0.1
<155	1	0.0
<160	0	0.0
<165	0	0.0
<170	1	0.0
<175	1	0.0
<180	1	0.0
<185	0	0.0
<190	0	0.0
<195	0	0.0
<200	0	0.0
<205	1	0.0
<210	0	0.0
<215	1	0.0
<220	0	0.0
<225	1	0.0
<230	2	0.1
<235	2	0.1
<240	3	0.1
<245	1	0.0
<250	1	0.0
≥250	12	0.8

MEAN= 15.1611

MEAN SQUARE= 1686.6814

STANDARD DEVIATION= 38.1641

CENTROIDS USED= 1461

DOT-RDOT STATISTICS,FLAG TEST AND RANGE TEST

DOT-RDOT	NUMBER	PERCENT
< 5	650	46.9
< 10	382	27.5
< 15	167	12.0
< 20	81	5.8
< 25	38	2.6
< 30	24	1.6
< 35	14	1.0
< 40	18	1.3
< 45	7	0.5
< 50	4	0.3

MEAN= 7.6904

MEAN SQUARE= 125.4215

STANDARD DEVIATION= 8.1328

CENTROIDS USED= 1385

FLAGS

FLAG 1 SET= 1789 PERCENT= 92.3
FLAG 2 SET= 1762 PERCENT= 90.9
FLAGS 1 AND 2 SET= 1613 PERCENT= 83.1
FLAG 3 SET= 24 PERCENT= 1.1
FLAG 4 SET= 31 PERCENT= 1.5
FLAG 8 SET= 38 PERCENT= 1.9

FLAG10 SET= 36 PERCENT= 1.8

Run 7 - Firm Track Centroids Only

< 70	1	2.3
< 75	0	0.0
< 80	0	0.0
< 85	0	0.0
< 90	0	0.0
< 95	0	0.0
<100	0	0.0
<105	1	2.3
<110	1	2.3
<115	0	0.0
<120	0	0.0
<125	0	0.0
<130	0	0.0
<135	0	0.0
<140	0	0.0
<145	0	0.0
<150	0	0.0
<155	0	0.0
<160	0	0.0
<165	0	0.0
<170	0	0.0
<175	0	0.0
<180	0	0.0
<135	0	0.0
<190	0	0.0
<195	0	0.0
<200	0	0.0
<205	0	0.0
<210	0	0.0
<215	0	0.0
<220	0	0.0
<225	0	0.0
<230	0	0.0
<235	0	0.0
<240	0	0.0
<245	0	0.0
<250	0	0.0
≥250	1	2.3

MEAN= 29.0039

MEAN SQUARE= 8151.1183

STANDARD DEVIATION= 85.4922

CENTROIDS USED= 43

DOT-RDOT STATISTICS,FLAG TEST AND RANGE TEST

DOT-RDOT	NUMBER	PERCENT
< 5	17	44.6
< 10	9	23.6
< 15	6	15.8
< 20	0	0.0
< 25	1	2.6
< 30	3	7.9
< 35	0	0.0
< 40	0	0.0
< 45	0	0.0
< 50	2	5.3

MEAN= 9.6680

MEAN SQUARE= 221.5317

STANDARD DEVIATION= 11.3125

CENTROIDS USED= 38

FLAGS

FLAG 1 SET= 95 PERCENT= 78.5
FLAG 2 SET= 70 PERCENT= 57.8
FLAGS 1 AND 2 SET= 44 PERCENT= 36.3
FLAG 3 SET= 0 PERCENT= 0.0
FLAG 4 SET= 0 PERCENT= 0.0
FLAG 8 SET= 2 PERCENT= 1.6
FLAG10 SET= 1 PERCENT= 0.8

APPENDIX B

ASR RADAR TRACKER

Abstract

A tracking program must be written to accept centroid data from the mag tapes collected in Miami and scan-to-scan correlate the centroids into tracks. The program is to be run on the CSEL computers. This memo details the method and critical parameters to be used by the tracker for the ASR radar.

1. Introduction

As a result of the Multisensor T&E Support Test in Miami, three types of data must be analyzed; target centroids seen by ASR radar, target centroids seen by ASR beacon, and target centroids seen by the ARSR radar and/or beacon. These centroids must be translated into tracks. This text details the method and critical parameters to be used to track the ASR radar centroids. Subsequent text will cover the ASR beacon and the ARSR.

The program is to be run on the CSEL computers. It is suggested that the tracker detailed here be programmed in modular form because the other trackers to be designed will have a similar structure.

2. ASR Radar Centroid Tracker

Centroid data is input to the program from 7 track, 556 bpi mag tape. The centroids are stored in bearing order in the Centroid Store. Centroids are used to update existing tracks and declare new tracks.

There are four types of tracks:

(1) fixed - a slow moving or stationary track that has established a definite scan-to-scan correlation.

(2) firm - a moving track whose velocity $\geq$ 70 knots and has established a definite scan-to-scan correlation

(3) tentative - a track which has not yet established a definite scan-to-scan correlation

(4) new tentative - a track which has just entered the system.

A track is updated in a zone behind the zone of the centroids being input from mag tape. There are 256 zones per radar scan. For example, fixed tracks are updated four zones (approximately 5.6°) behind the zone of centroids being input. A window is placed around the predicted position of the track for the present scan and the Centroid Store is searched to determine if a centroid is within the window. If no centroids are found, a second search may be used.

If no centroids are found for a track, a miss is declared and the track coasted or dropped. Tracks that find a centroid are updated with a variable gain α,β filter. Range α,β vary as a function of time and correlation success. Bearing α,β vary as a function of time, range, and correlation success. When a track is coasted, $\alpha = \beta = 0$. After all tracks in a zone have been updated, any remaining uncorrelated centroid is entered as a new tentative track.

Track promotion or drop is detailed in the state diagram in Figure 2.1 which also details the major features and data flow of the program.

3. Executive Routine (EXEC)

The Executive routine insures that the program is running properly, controls data I/O, and updates tracks in an orderly fashion. The routine begins (Figure 3.1) by reading a block of centroid data from the mag tape unit which is processed and placed in the Centroid Store in bearing order. The Centroid Store will hold 512 centroids with two 30-bit words per centroid. The first word contains:

(1) range - eleven bits with an LSB = 1/16 nmi

(2) bearing - twelve bits, BAM

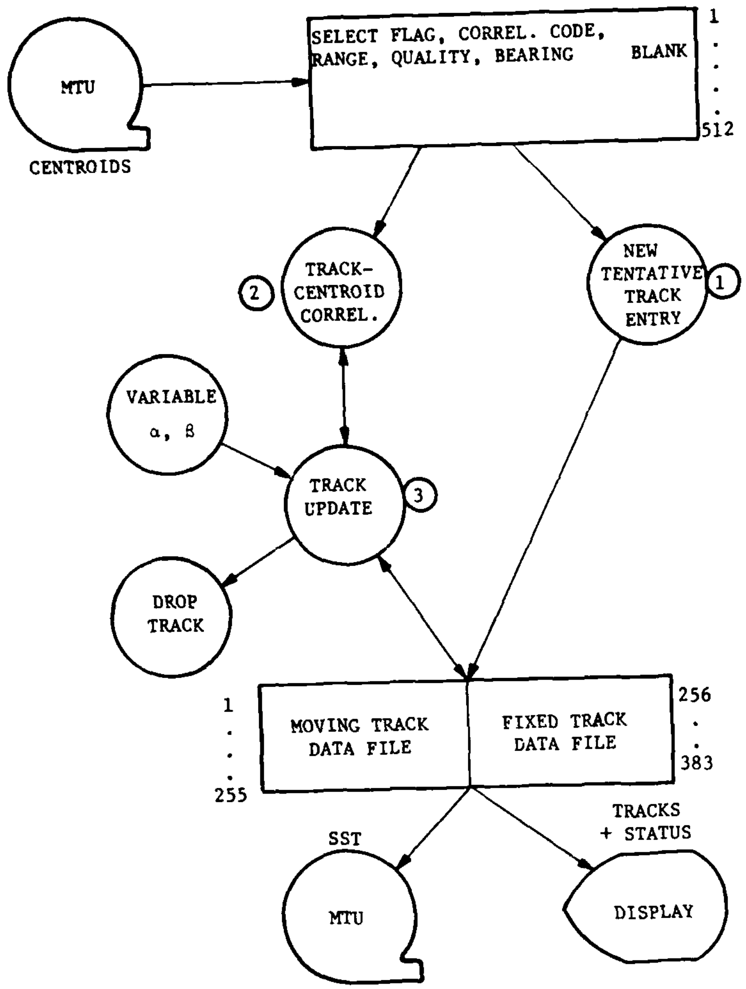
(3) selected flag - one bit which is set when the centroid is selected to update a track

(4) correlated flag - two bit code which indicates that the centroid correlated with a tentative (including new tentative), firm, or fixed track

(5) radar quality - four bit code indicating centroid quality. The larger the code, the better the centroid.

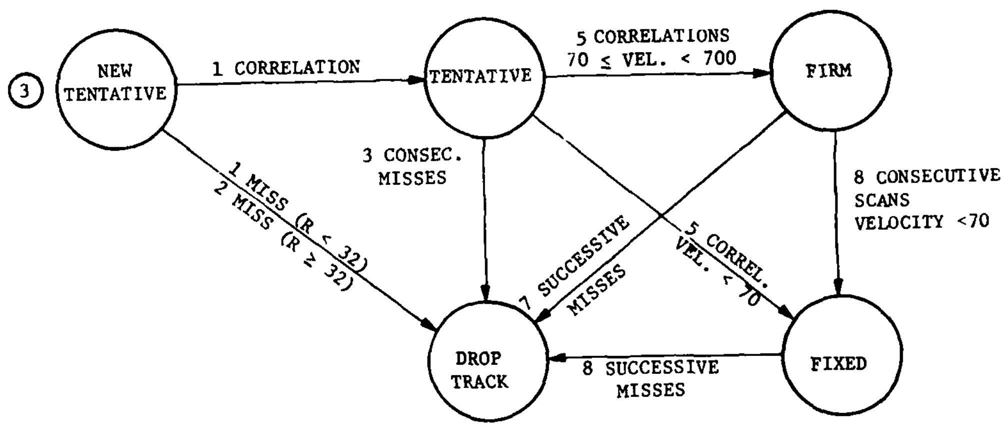
The second word is blank but will be used in trackers using beacon data.

The bearing of the last centroid input from the block of mag tape is used to determine the "new zone". If (new zone-old zone) $\geq$ 1, the "old" zone is incremented and a check is made for data output to the MTU. Output data is to be in an SST format. Output will occur at zone 0. The time to be written on the MTU will be the interpolation of the time when the radar crossed 0°. This can be obtained by interpolating between the centroids received immediately before and after 0°.



2

TRACK TYPE	UPDATE POSITION	RANGE WINDOW	BEARING WINDOW	POSSIBLE SECOND SEARCH?
FIXED	ZONE - 4	$\pm.219$ NMI	$\pm 1.12° + \frac{4.4}{R}$	NO
FIRM	ZONE - 12	$\pm.156$	$\pm 1.12° + \frac{4.84}{R}$	YES
TENTATIVE	ZONE - 21	$\pm.156$	$\pm 1.12° + \frac{4.84}{R}$	YES
NEW TENTATIVE	ZONE - 30	$\pm.781$	$\pm 1.12° + \frac{44.5}{R}$	NO
2nd SEARCH	SAME AS 1st	$\pm.219$	$\pm 1.67° + \frac{7.25}{R}$	-



1 AFTER ALL TRACKS IN A ZONE HAVE BEEN UPDATED, ENTER AN UNCORRELATED CENTROID AS A NEW TENTATIVE TRACK.

FIGURE 2.1 MAJOR FEATURES OF TRACK LOGIC

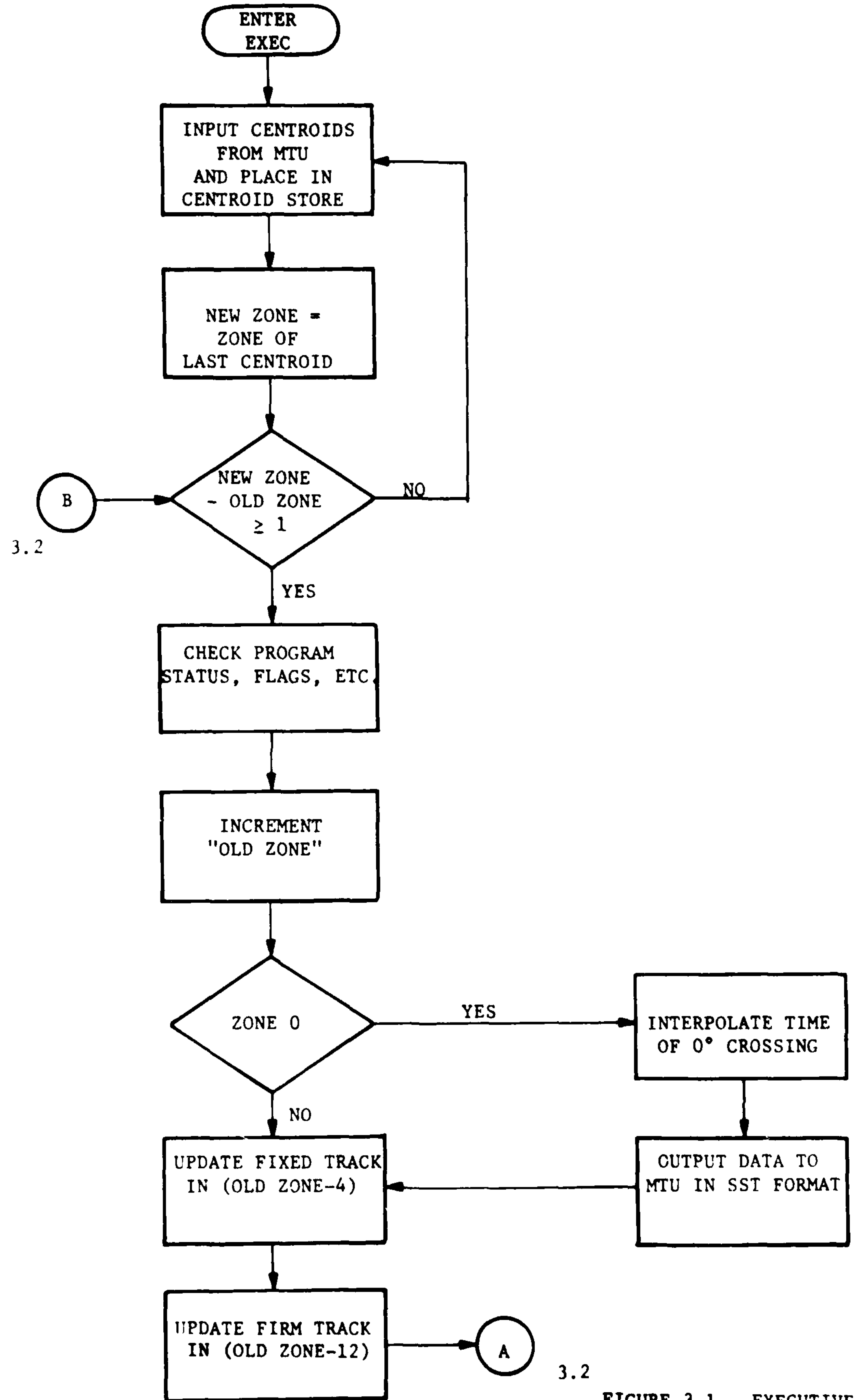


FIGURE 3.1 EXECUTIVE ROUTINE

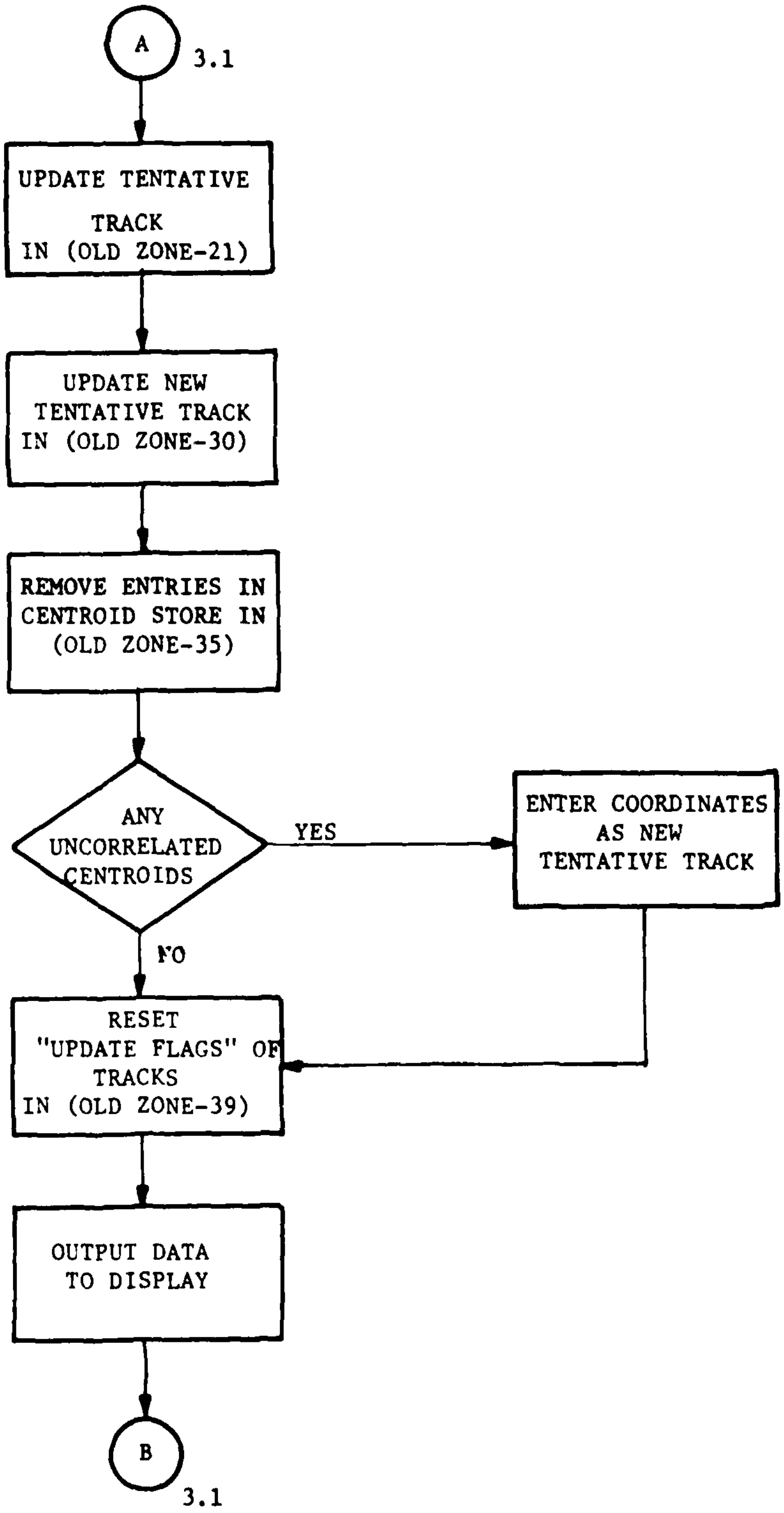


FIGURE 3.2 EXECUTIVE ROUTINE (cont'd)

Next, all fixed tracks in (old zone -4) are updated, firm tracks in (old zone -12), tentative tracks in (old zone -21), new tentative tracks in (old zone -30). Entries in the Centroid Store in (old zone -35) are removed from the Centroid Store. Any of the removed centroids whose "correlated flag" has not been set are entered as new tentative tracks. Then the "update flag" is reset for all tracks in (old zone -39). New data is output to the display and the EXEC loop is repeated.

4. Fixed Track Update Routine (FXUP)

The Fixed Track Update routine starts by searching the Centroid Store. Any centroid which was not previously selected to update another track will be used to update this fixed track. The update procedure merely inserts the centroid coordinates into the fixed track coordinate stores and clears the "missed scans" count. If a suitable centroid is not found, the "missed scans" count is incremented. A fixed track is dropped on the eighth consecutive miss.

5. Firm Track Update Routine (FMUP)

The Firm Track Update routine (Figure 5.1) begins by searching the Centroid Store. If one uncorrelated centroid or one unselected centroid is found, it is used to update the track. If more than one, multiple track logic is entered (Figure 5.3). If none, the search window is expanded and the same questions asked. If no suitable centroids are found by the second search, the "missed scans" counter is incremented and the track is coasted. On the seventh miss the firm track is dropped.

After the track is updated, either by coasting or with a centroid, the track is dropped if:

(1) range $\leq$ 1 nmi

(2) velocity $\geq$ 756 knots on eight consecutive scans.

A firm track is promoted to fixed track if its velocity < 70 knots on eight consecutive scans.

6. Tentative Track Update Routine (TTUP)

Tentative tracks are updated with a centroid if:

(1) any uncorrelated centroids are found during the first search of the Centroid Store

(2) any uncorrelated centroids are found during the second search

(3) any unselected centroids are found and no "previously correlated with fixed" are found on the second search.

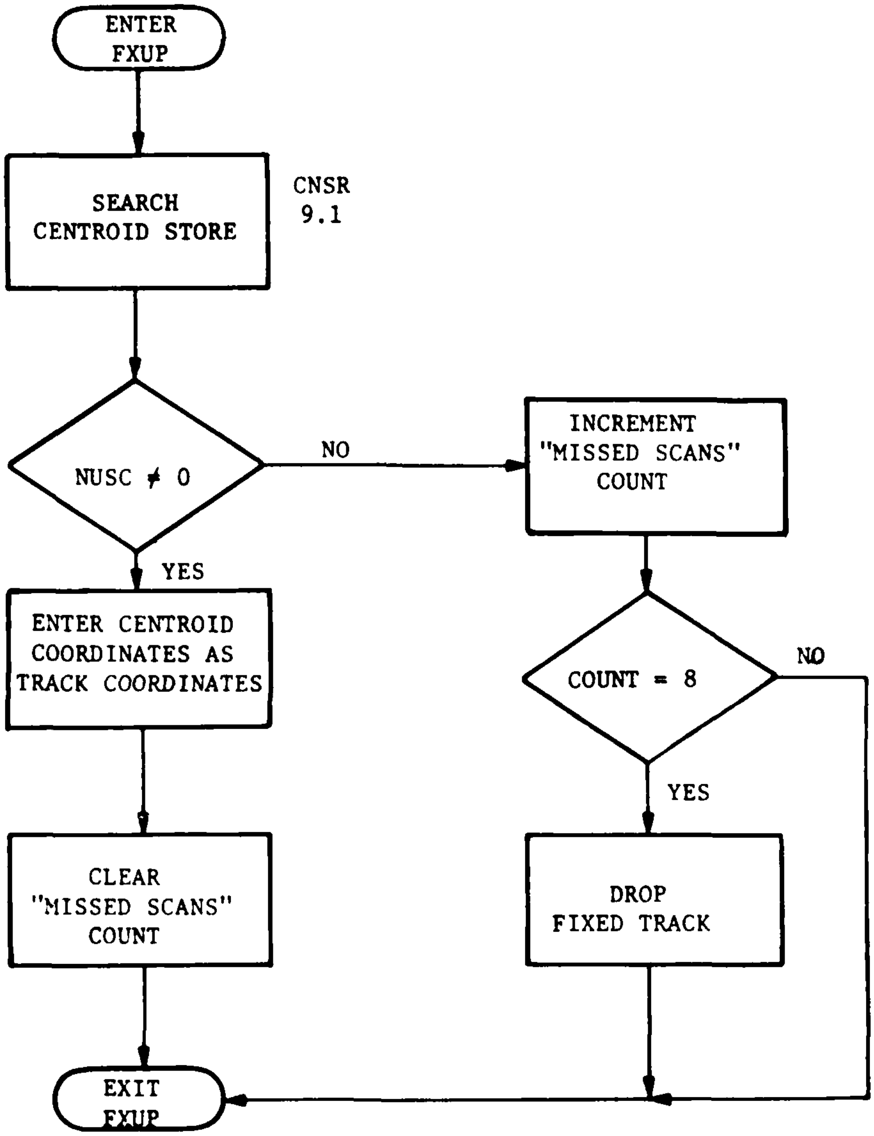


FIGURE 4.1 FIXED TRACK UPDATE ROUTINE

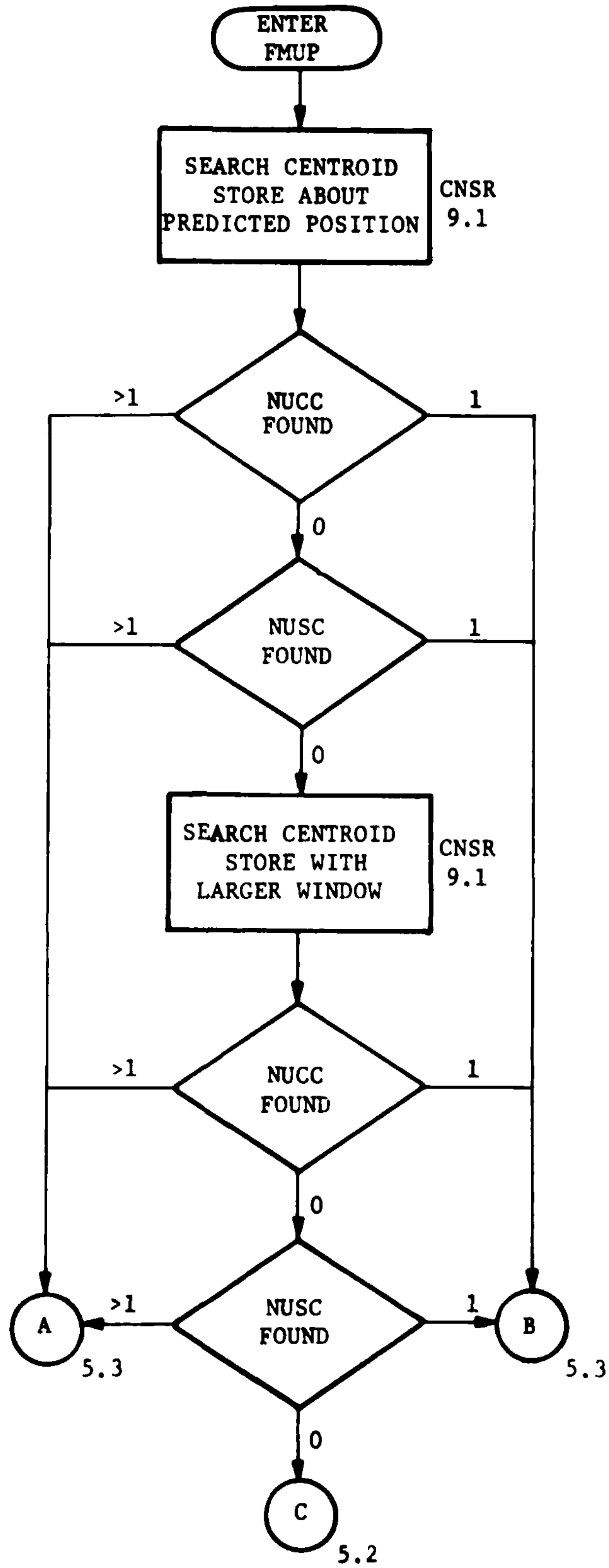


FIGURE 5.1 FIRM TRACK UPDATE ROUTINE

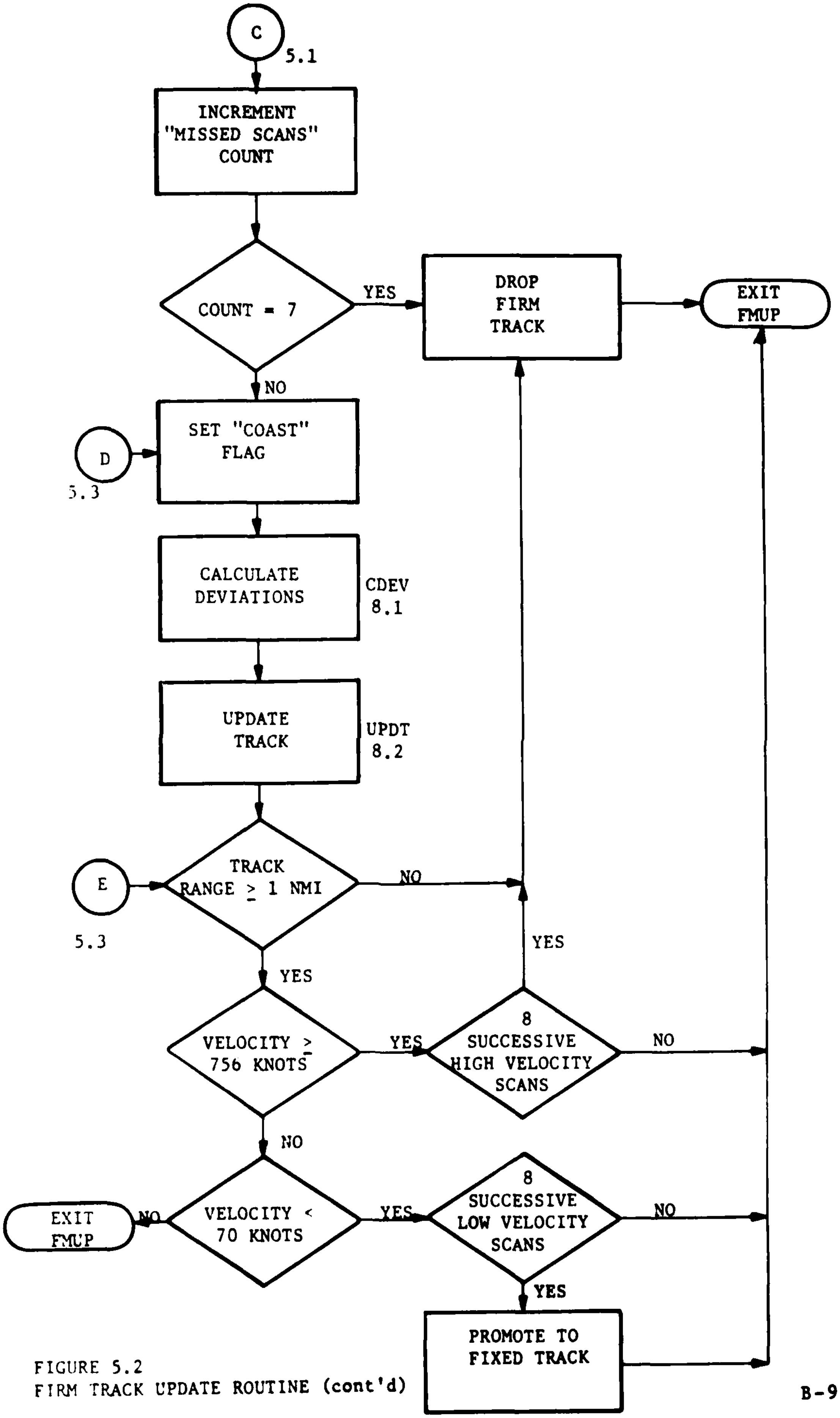


FIGURE 5.2
FIRM TRACK UPDATE ROUTINE (cont'd)

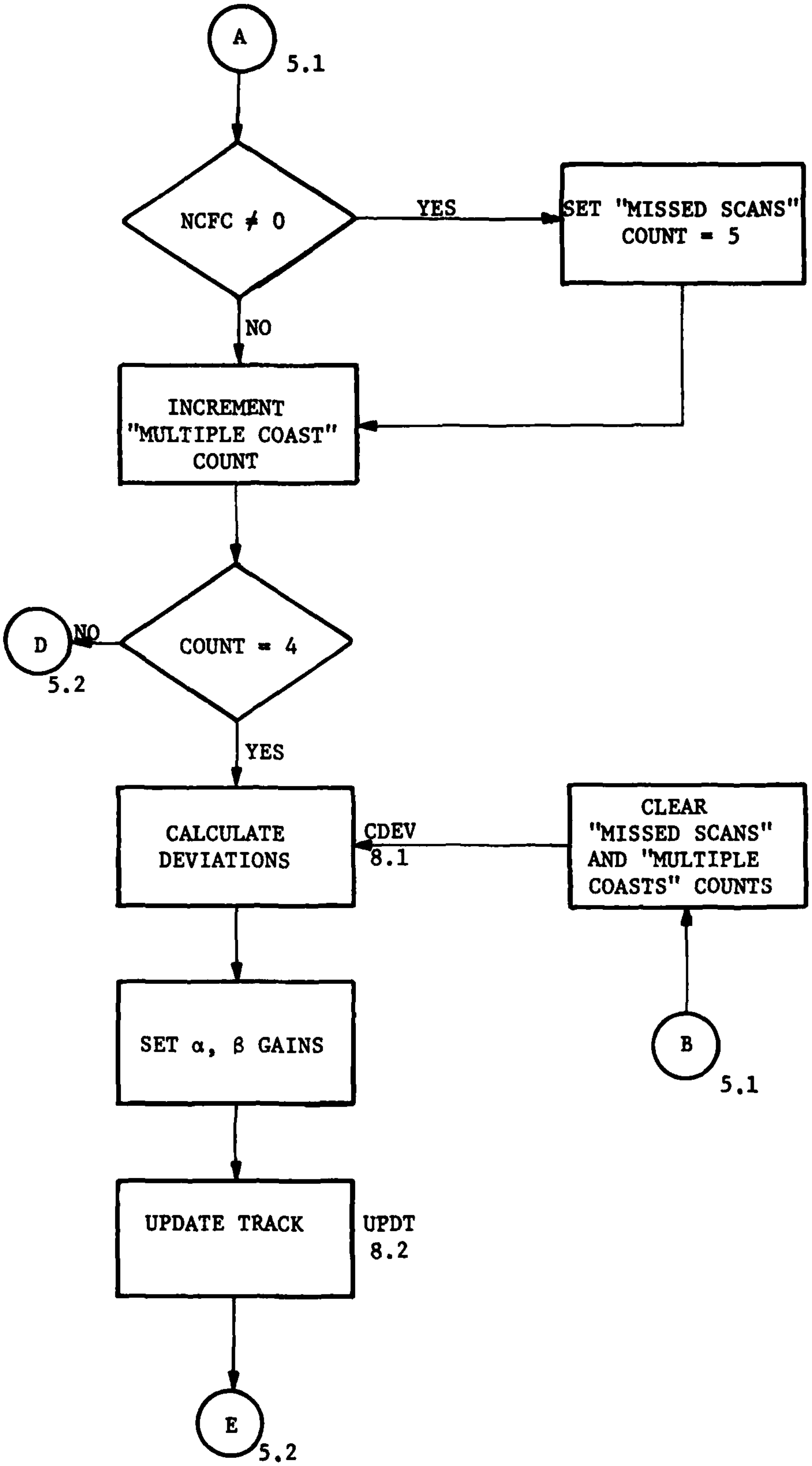


FIGURE 5.3 FIRM TRACK UPDATE ROUTINE (cont'd)

A tentative track is dropped on the third consecutive miss (Figure 6.1).

After update, the track is dropped if its range $\leq$ 1 nmi. On the sixth update with a centroid, the track is promoted to fixed if its velocity < 70 knots, to firm if (70 knots $\leq$ velocity $\leq$ 700 knots), and dropped if velocity > 700 knots.

7. New Tentative Track Update Routine (NTUP)

The New Tentative Track Update routine begins by searching the Centroid Store. If any centroids were found which previously correlated with fixed track, the track is dropped. If any uncorrelated centroids are found, the track is updated by the Tentative Track Update routine. If none are found the track is dropped unless the range of the track exceeds 32 nmi where one miss is allowed.

8. Tracking Subroutines

See Figure 8.1 for the Calculate Deviations subroutine and Figure 8.2 for the Update Track subroutine.

9. Centroid Search Routine (CNSR)

The Centroid Search routine determines the best centroid to be used for track update. The routine begins by placing a window around the predicted position of the track for the present scan when tentative or firm tracks are involved. For fixed and new tentative tracks, the last measured position is used. Range window sizes are given in Figure 9.1. Bearing windows are given by:

$$\text{B.W.} = \pm \left(C_1 + \frac{C_2}{R} \right)$$

where C_1 and C_2 are given in Figure 9.1 and R = track range in nautical miles. Maximum bearing window = 5.63°.

If it is the first search in the present scan for this track, the window sizes are saved for use by the Set α, β routine. The Centroid Store is searched and if a centroid is found within the search window, the "correlated" flag is checked. NCFC is incremented if the flag indicates the centroid previously correlated with a fixed track. NUSC is incremented if the "correlated" flag is set but the "selected" flag is not set. If the "correlated" flag is not set, NUCC and NUSC are incremented and the track code is placed in the "correlated" flag.

If several centroids are found in the search window, an uncorrelated centroid will be selected to update a track over an unselected centroid. Centroids with the "selected" flag set cannot be used for track update. If several uncorrelated centroids

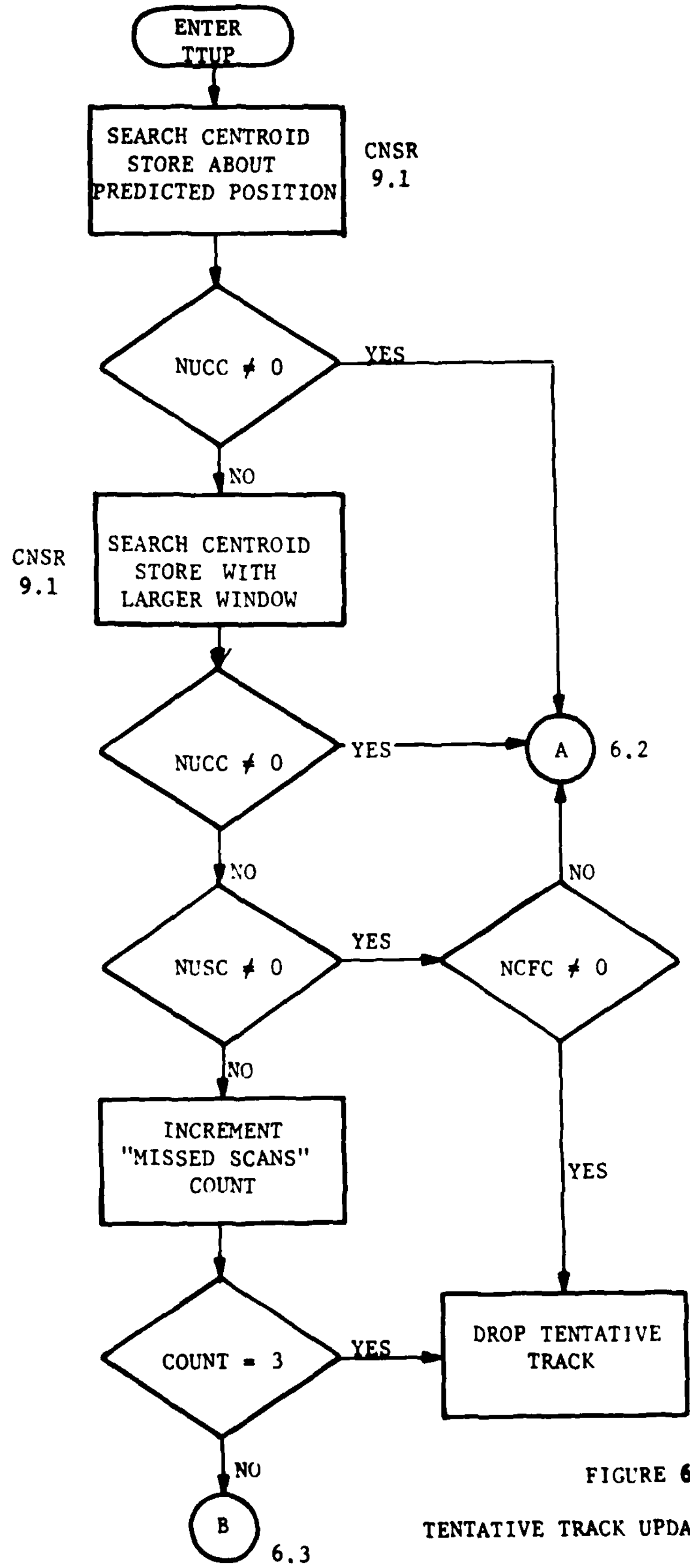
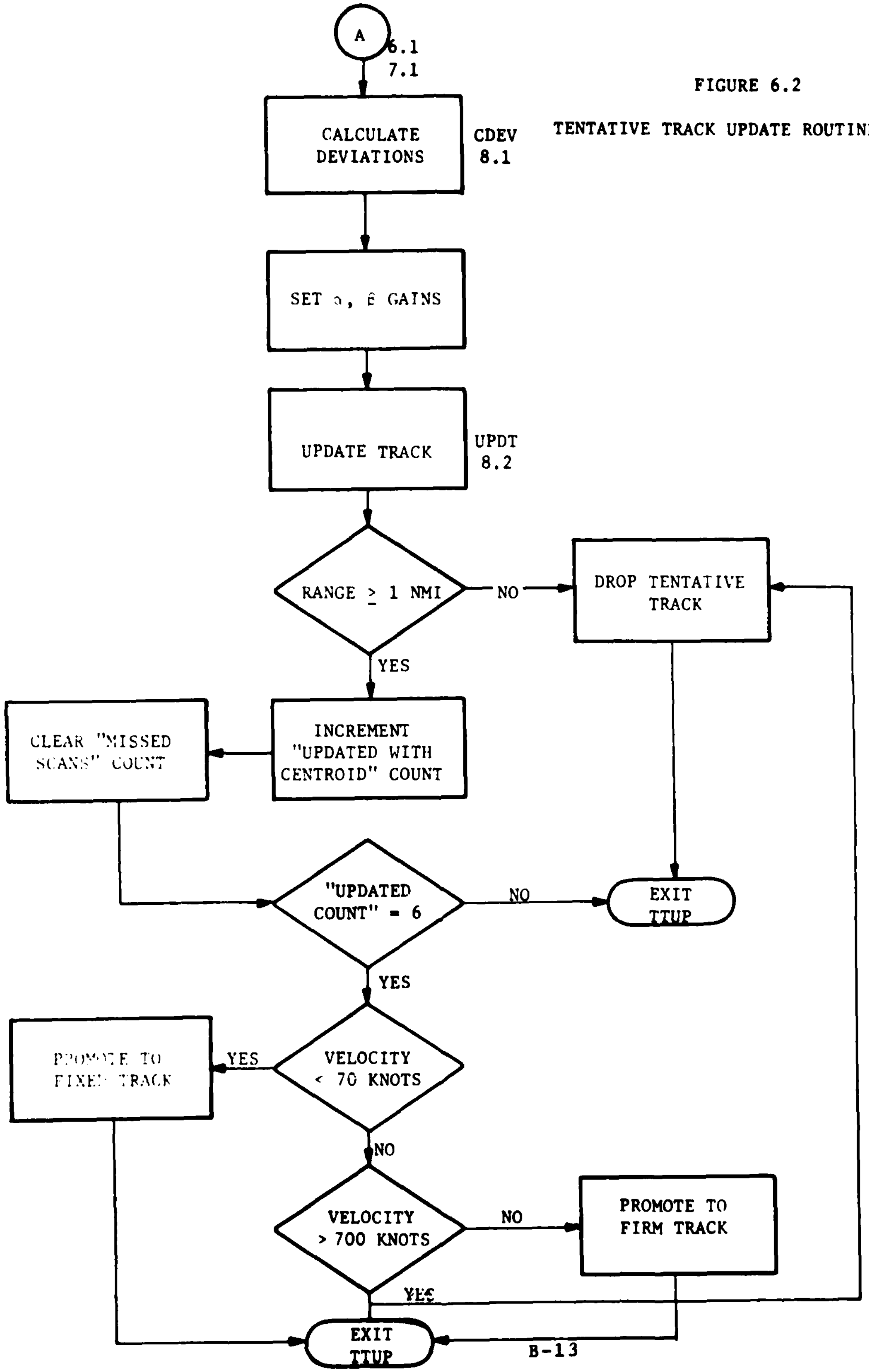


FIGURE 6.1

TENTATIVE TRACK UPDATE ROUTINE

FIGURE 6.2

TENTATIVE TRACK UPDATE ROUTINE (cont'd)



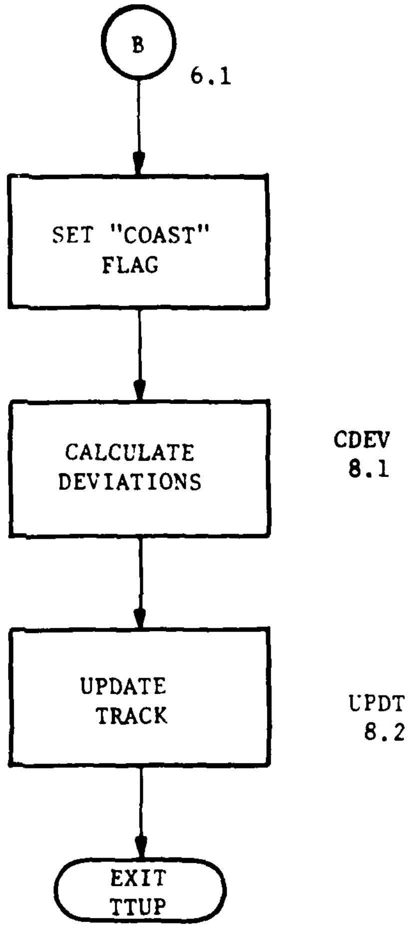


FIGURE 6.3 TENTATIVE TRACK UPDATE ROUTINE (cont'd)

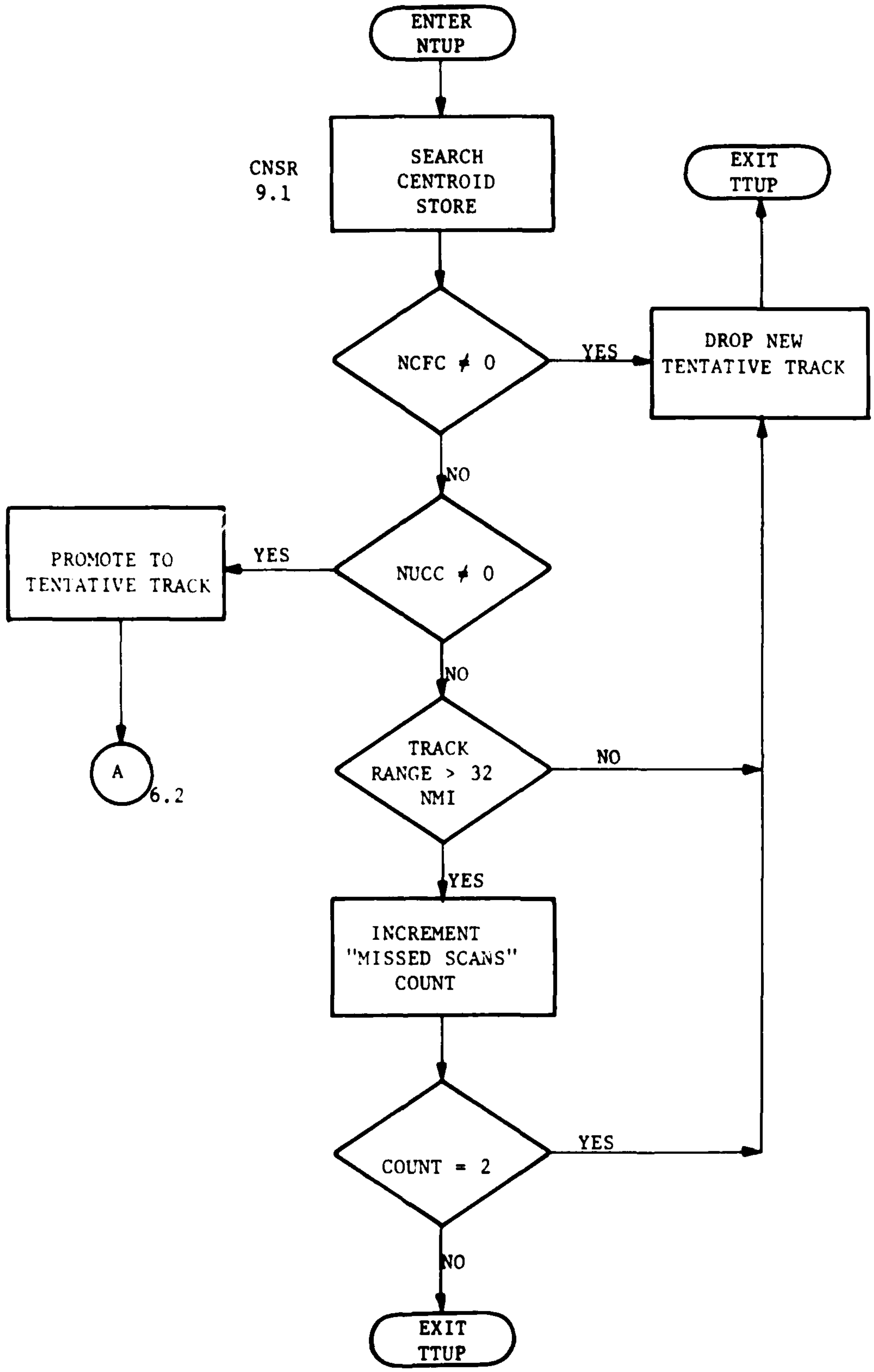
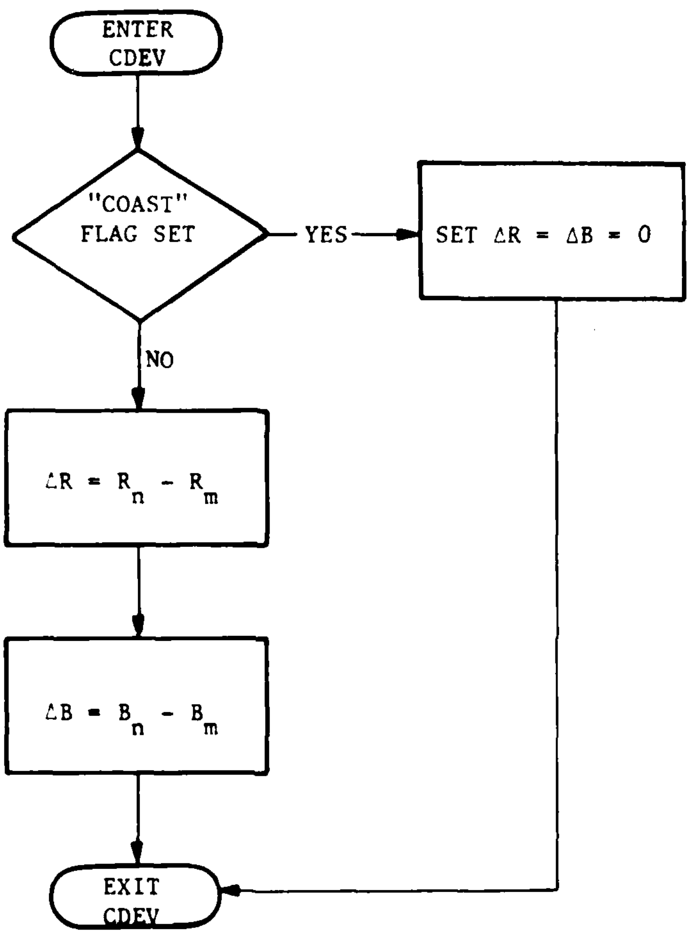


FIGURE 7.1 NEW TENTATIVE TRACK UPDATE ROUTINE



8.1 CALCULATE DEVIATIONS SUBROUTINE (CDEV)
R_n = PREDICTED RANGE CALCULATED ON THE PREVIOUS SCAN.
R_m = MEASURED RANGE ON THE PRESENT SCAN = CENTROID RANGE.

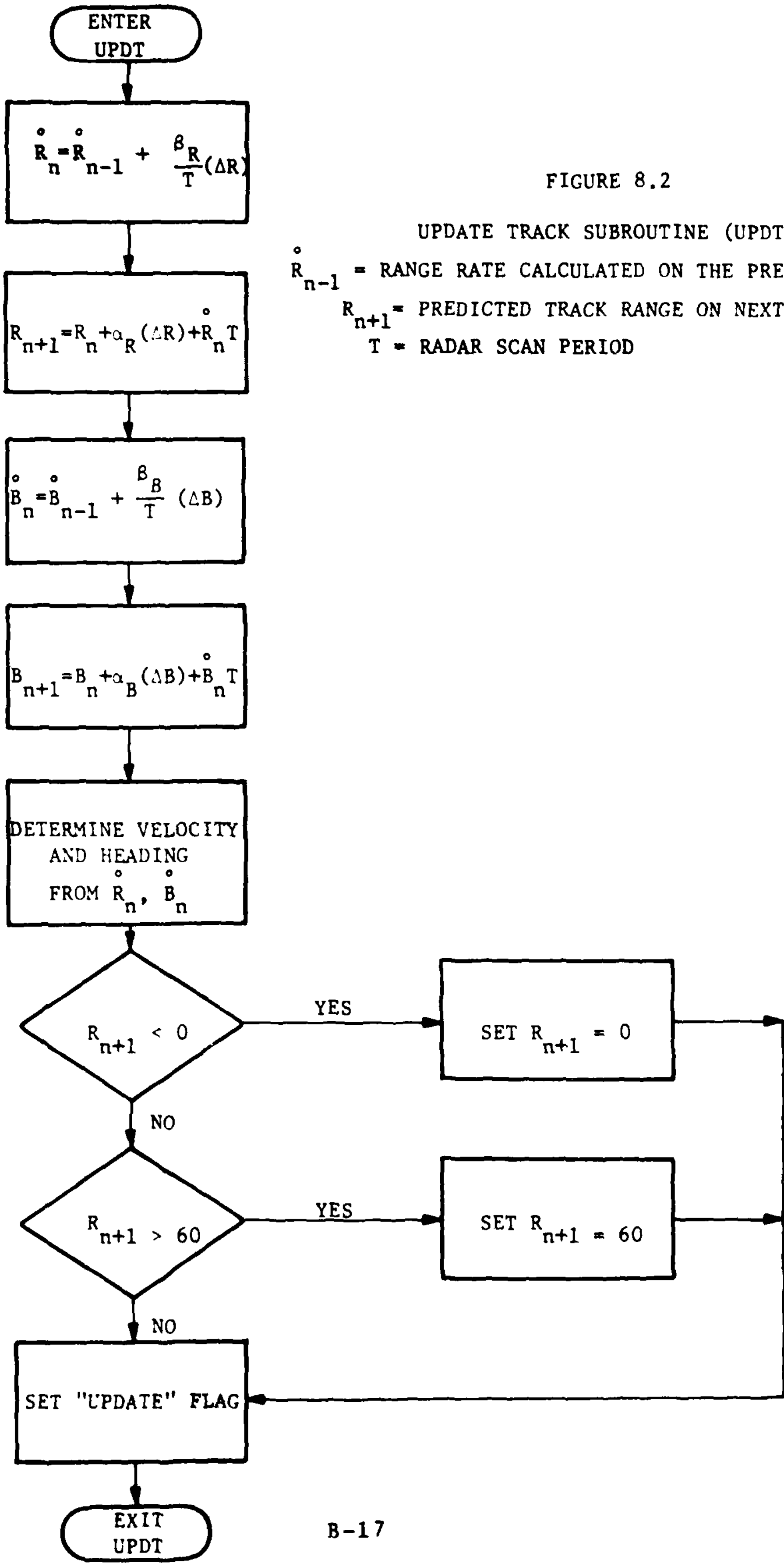


FIGURE 8.2

UPDATE TRACK SUBROUTINE (UPDT).

$\dot{R}_{n-1}$ = RANGE RATE CALCULATED ON THE PREVIOUS SCAN.

R_{n+1} = PREDICTED TRACK RANGE ON NEXT SCAN.

T = RADAR SCAN PERIOD

TRACK TYPE	RANGE WINDOW	C_1	C_2
New tentative	$\pm$ .781 nmi	1.12°	44.5°
Tentative + firm	$\pm$ .156 nmi	1.12°	4.62°
Fixed	$\pm$ .219 nmi	1.12°	4.40°
Second Search for Tentative + firm	$\pm$ .219 nmi	1.67°	7.03°

FIGURE 9.1

SEARCH WINDOW PARAMETERS

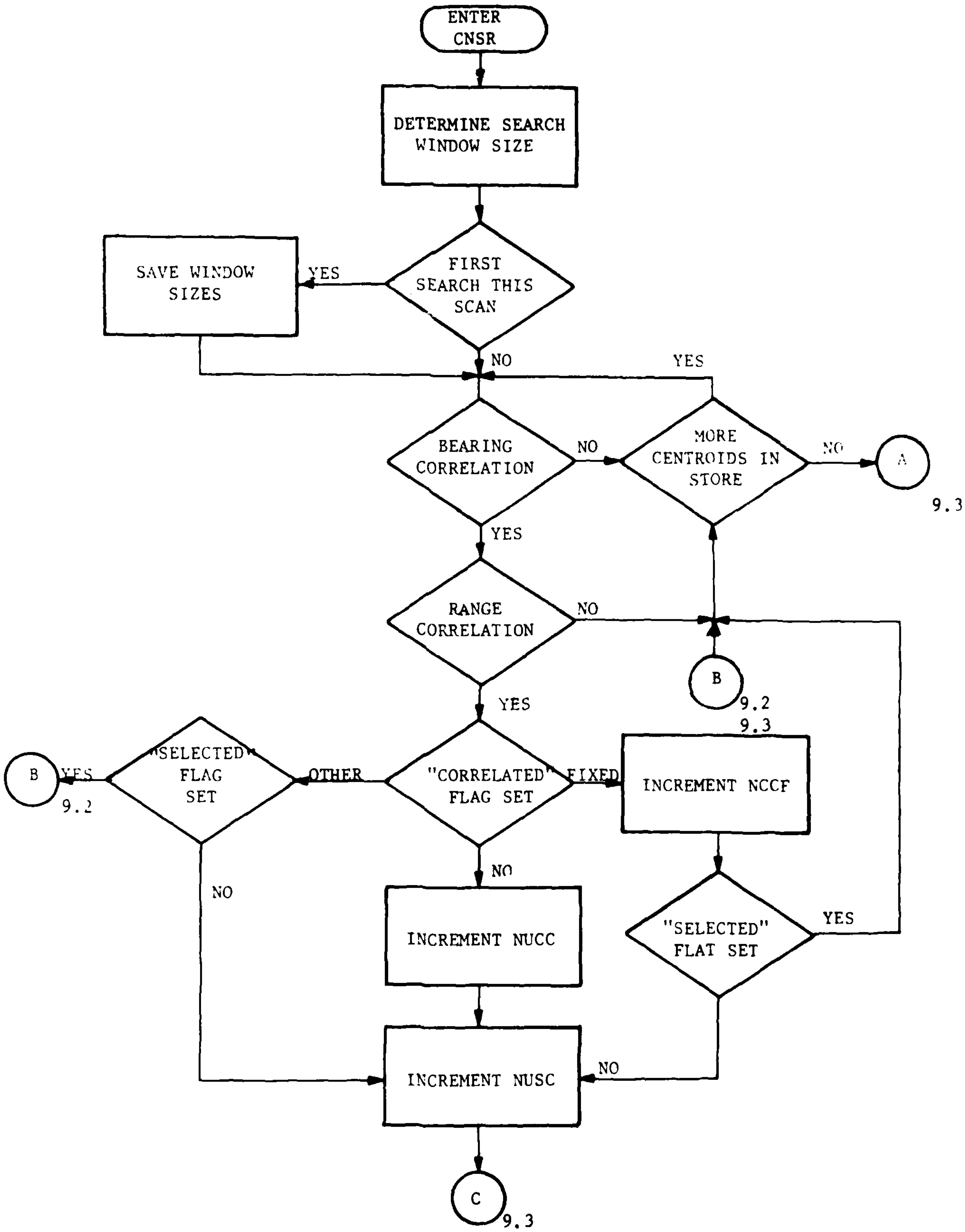
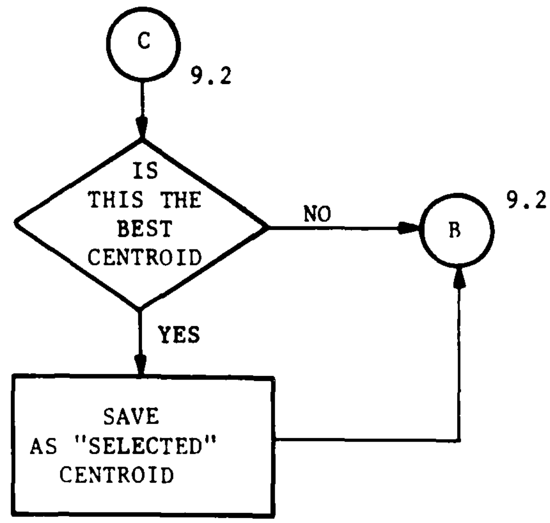


FIGURE 9.2 CENTROID SEARCH ROUTINE



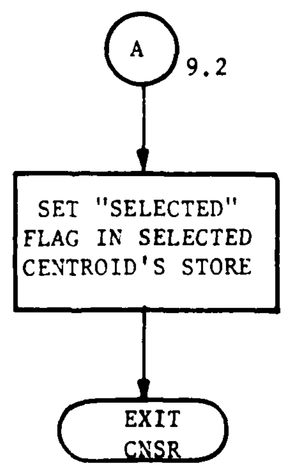


FIGURE 9.3 CENTROID SEARCH ROUTINE (cont'd)

are found (or several unselected centroids and no uncorrelated centroids), the centroid with the larger "quality" will be selected for updating the track. The "selected" flag is set only for the centroid selected for update. Its coordinates along with the counters NCFC, NUCC, and NUSC are saved for use by the track update routines.

10 Set α, β Routine

A table of gains is shown in Figure 10.1. Gains $\alpha = 1$, $\beta = .5$ are used only for new tentative tracks beyond 32 nmi that had one missed scan. For tentative track gains, the word "update" refers to track updates with a centroid (e.g. third update is the third update of a track with a centroid).

"Large window" gains are used only on those coordinates whose Δ exceeded the first search window. For example, if ΔR is calculated to be .2 for a firm track, the first search range window was $\pm$ .156 and therefore the large window α_R, β_R are used. However, the decision on using firm track or large window α_B, β_B depends on the magnitudes of ΔB and the first search bearing window.

α_R	β_R	α_B	β_B	TIME OF USE
1	1	1	1	Update of new tentative track
1	.5	1	.5	Update of new tentative track that missed one scan
.839	.518	.879	.641	Tentative track, second update, short range
.839	.518	.844	.531	, medium "
.839	.518	.836	.508	, long "
727	.356	.844	.609	Tentative track, third update, SR
.727	.356	.750	.406	, MR
.727	.356	.707	.32	, LR
.665	.302	.844	.609	Tentative track, fourth update, SR
.665	.302	.711	.375	, MR
.665	.302	.621	.234	, LR
.639	.29	.844	.609	Tentative track, fifth update , SR
639	.29	.699	.375	, MR
.639	.29	.566	.195	, LR
63	.29	.844	.609	Firm, tentative sixth update , SR
.63	.29	.699	.375	, MR
63	.29	.516	.180	, LR
.727	.356	.879	.641	Firm + tentative large window , SR
727	.356	.750	.406	, MR
.727	356	.707	.320	, LR

FIGURE 10.1 TRACKER GAINS

SR = (range $<$ 6.25 nmi),
MR = (6.25 nmi $\leq$ range $\leq$ 15 nmi)
LR = (range $>$ 15 nmi)

APPENDIX C

SUMMARY OF INTERNAL MEMORANDA GENERATED FOR THE MTD UTILIZATION EFFORT

F3E-603, "Comments on 'MTD Utilization Meeting' at NAFEC, November 5, 1975", F. R. Castella and S. F. Haase, November 12, 1975

F3E-617, "On the Relative Merits of the MTD and RVD-4 Video Processors", J. T. Miller, December 10, 1975

F3E-621, "Preliminary Recommendations for the Utilization of MTD Doppler Data", F. R. Castella and J. T. Miller, December 11, 1975

F3E-658, "Proposed Extension to MTD Study", J. T. Miller, February 10, 1976

F3E-683, "Proposed MTD Software Development", J. T. Miller, March 5, 1976

F3B-806-1, "MTD Anomalous Detections", F. R. Castella, March 24, 1976

F3E-703, "Some Single Range Bin Characteristics of MTD Raw Data", M. J. Feil, April 6, 1975

F3B-819-1, "MTD Initial Experimental Centroid Description", F. R. Castella and C. L. Roe, April 6, 1976

F3B-840-1, "Some MTD Display Results Using the Experimental Centroid Algorithm", F. R. Castella and C. L. Roe, April 27, 1976

F3B-865-1, "Evidence of Second Time Around Aircraft with MTD Data", F. R. Castella, May 21, 1976

F3E-739, "Statistical Information of the MTD Raw Data Extraction Tape", M. J. Feil, June 9, 1976

F3E-739A, "Statistical Information of the MTD Raw Data Extraction Tape", (additions to F3E-739), M. J. Feil, July 8, 1976

F3E-746, "Review of 'Design Data for Moving Target Detector'", J. T. Miller and F. R. Castella, June 28, 1976

F3B-901-1, "Computer Run Instructions for FAA Programs",C. L. Roe, June 30, 1976